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ANALYSIS OF LONG PERIOD SEISMIC SIGNALS AND NOISE RECORDED AT LASA, TFO AND UBO

19 June 1970

Prepared For

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C.

BY

Robert P. Massé

Don M. Clark

Herman J. Mecklenburg

SEISMIC DATA LABORATORY

Under
Project VELA UNIFORM



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ANALYSIS OF LONG PERIOD SEISMIC SIGNALS AND NOISE RECORDED AT LASA, TFO AND UBO

SEISMIC DATA LABORATORY REPORT NO. 254

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ABSTRACT

Long period signals recorded at the seismic arrays UBO, TFO and LASA were analyzed to determine the fundamental mode Rayleigh wave dispersion curves for paths from different source areas to each of the arrays. These paths are mixed continental and oceanic, and the dispersion curves calculated fall within the range between the average dispersion for a pure continental path and that for a pure oceanic path. Analysis of the long period noise (15 to 50 seconds) recorded at each array shows the rms value to be in the 8 to 20 mu range. Simple beamforming gives approximately N²db reduction in noise at all arrays. Using a group velocity of 3.5 km/sec results in signal loss for some events in the LASA beams.

TABLE OF CONTENTS

	Pag	e No
ABSTRACT		
INTRODUCTION		1
RAYLEIGH WAVE GROUP VELOCITY DISPERSION		2
ANALYSIS OF ARRAY BEAMS		4
CONCLUSIONS		8
REFERENCES		9

LIST OF FIGURES

Figure Titl	е		Figure	No
Dispersion waves from	of an	fundamental mode Rayleigh event in Albania.	1	
Dispersion waves from	of an	fundamental mode Rayleigh event in the North Atlantic.	2*	4
Dispersion waves from Ridge.	of an	fundamental mode Rayleigh event in the North Atlantic	3	
Dispersion waves from	of an	fundamental mode Rayleigh event in the Balleny Islands.	4	
Dispersion waves from	of an	fundamental mode Rayleigh event in Costa Rica.	5	
Dispersion waves from	of an	fundamental mode Rayleigh event in El Salvador.	6	
Dispersion waves from	of an	fundamental mode Rayleigh event in the Galapagos.	7	
Dispersion waves from	of an	fundamental mode Rayleigh event in Hindu Kush.	8	,
Dispersion waves from	of an	fundamental mode Rayleigh event in Hokkaido.	9	
Dispersion waves from	of an	fundamental mode Rayleigh event in the Kermadec Islands	. 10	til
Dispersion waves from	of an	fundamental mode Rayleigh event in the Kodiac Islands.	11	
Dispersion waves from	of an	fundamental mode Rayleigh event in the Kurile Islands.	12	
Dispersion	of	fundamental mode Rayleigh event in the Kurile Islands.	13	

Figure Title ,	Figure No
Dispersion of fundamental mode Rayleigh waves from an event in West New Guinea.	14
Dispersion of fundamental mode Rayleigh waves from an event in Nicaragua.	15
Dispersion of fundamental mode Rayleigh waves from an event in the Rat Islands.	16
Dispersion of fundamental mode Rayleigh waves from an event in Sinkiang.	17
Dispersion of fundamental mode Rayleigh waves from an event in the Solomon Islands.	18
Dispersion of fundamental mode Rayleigh waves from an event in the Unimak Islands.	19
Dispersion of fundamental mode Rayleigh waves from an event in Yugoslavia.	20
Low pass and band pass filters used in long period data processing.	21
Band pass filtered noise and signal traces with unphased and phased sums for an event in Albania recorded at UBO.	22
Band pass filtered noise and signal traces with unphased and phased sums for an event in Argentina recorded at UBO.	23
Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic recorded at UBO.	24
Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic Ridge recorded at UBO.	25

Figure Title	Figure No
Band pass filtered noise and signal traces with unphased and phased sums for an event at the Coast of Chile recorded at UBO.	26
Band pass filtered noise and signal traces with unphased and phased sums for an event in Costa Rica recorded at UBO.	27
Band pass filtered noise and signal traces with unphased and phased sums for an event in El Salvador recorded at UBO.	28
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Fox Islands recorded at UBO.	29
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Galapagos recorded at UBO.	30
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Hindu Kush recorded at UBO.	31 .
Band pass filtered noise and signal traces with unphased and phased sums for an event in Hokkaido recorded at UBO.	32
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kermadec Islands recorded at UBO.	33
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kodiac Islands recorded at UBO.	34
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kuril Islands recorded at UBO.	35
Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinea recorded at URO	36
in Euro view valuen recultien at unu.	3.0

Figure Title		Figure N
Band pass filtered noise and signal to with unphased and phased sums for an in Nicaragua recorded at UBO.		37
Band pass filtered noise and signal twith unphased and phased sums for an in the Rat Islands recorded at UBO.		38
Band pass filtered noise and signal to with unphased and phased sums for an in Sinkiang recorded at UBO.		39
Band pass filtered noise and signal to with unphased and phased sums for an in the Volcano Islands recorded at UBC	event	40
Band pass filtered noise and signal twith unphased and phased sums for an in Albania recorded at TFO.		41
Band pass filtered noise and signal twith unphased and phased sums for an in the North Atlantic recorded at TFO	event	42
Band pass filtered noise and signal to with unphased and phased sums for an in the North Atlantic Ridge recorded	event	43
Band pass filtered noise and signal twith unphased and phased sums for an in El Salvador recorded at TFO.		44
Band pass filtered noise and signal twith unphased and phased sums for an in the Fox Islands recorded at TFO.		45
Band pass filtered noise and signal twith unphased and phased sums for an in Galapagos recorded at TFO.		46

Figure Title	Figure	No
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Border Region of Greece - Albania recorded at TFO.	47	
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Hindu Kush recorded at TFO.	. 48	
Band pass filtered noise and signal traces with unphased and phased sums for an event in Hokkaido recorded at TFO.	49	
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kermadec Islands recorded at TFO.	50	
Band pass filtered noise and signal traces '' with unphased and phased sums for an event in the Kodiac Islands recorded at TFO.	51	•
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kurile Islands ecorded at TFO.	52	
Band pass filter and signal traces with unphased and sums for an event in East New Guinea recorded at TFO.	53	
Band pass filtered noise and signal traces with unphased and phased sums for an event in Nicaragua recorded at TFO.	54	
Band pass filtered noise and signal traces with unphased and phased sums for an event in Sinkiang recorded at TFO.	55	
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Volcano Islands recorded at TFO.	56	

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,	Fi	gı	ur	e	T	i ·	t 1	e	Ti																	6				Fig	ure	N	C
	Ba wi iņ	tl	h	ur	۱p	h	a s	e	d	a	n d		рh	as	e	d	S	uI	m s	1	f o	na	l ar	t	ra ev	ces	t				57 a		
	Ba wi in	t	h	ui	gr	h	a s	e	d	a	nd	۱ ا	ph	as	s e	d	S	u	m s	1	fo	na r	l ar	t	ra ev	ces	s t				57b		
	Ba wi in	t	h	u I	np	h	a s	e	d	a	n d	1	ph	a	s e	d	S	u	m s		fo	r	l aı	t n	ra ev	ces en	s t				58 a		
	Ba wi	t	h	u	n p	h	a s	e	d	a	nd	1	p h	a	s e	d	S	u	m s		fc	r	a	t	ra	ce: en:	s t				58b)	
	wi	t	h	u	np	h	as	e	d	a	nc	i	ph	a	s e	d	S	u	m s		fo	na r As	aı	n	ra ev	ce: en	s t				59a	14	
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	W.	it	h	u	n	o h	a	SE	d d	a	n	d	ph	ı a	Se	b e	9	s u	m	S	f	gn	a 1 a	n	tra ev	ce	s t				628	a	

Figure	Tit	le	•				•	1	Figure	No.
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No.

Figure Title	Figure
Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinea recorded at LASA.	67b
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Philippine Islands recorded at LASA.	68a
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Philippine Islands recorded at LASA.	68b
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Rat Islands recorded at LASA.	69a
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Rat Islands recorded at LASA.	69b
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Ryukyu Islands recorded at LASA.	70a
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Ryukyu Islands recorded at LASA.	70ь
Long period RMS noise levels at UBO, TFO and LASA.	71
Noise reduction of long period beams of UBO, TFO and LASA.	72
S/N improvement of long period beams of UBO, TFO and LASA.	73
Actual S/N improvement of long period UBO, TFO and LASA beams minus N ² .	74

LIST OF TABLES

Table Title		Table	No
Source Parameters of Events and the Specific Recording Instruments of the Arrays used in Computation of Group Velocity Dispersion		1	
Source Parameters of Events Analyzed by Beam Formation		2	
Amplitude Data for Vertical Component Long Period Array Beams with Individual Traces Band Pass Filtered		3	
Amplitude Data for Vertical Component Long Period Array Beams using LASA C or F Ring Instruments with Individual Traces Band Pass Filtered		4	
Amplitude Data for Vertical Component Long Period Array Beams with Individual Traces Low Pass Filtered	φN	. 5	
Amplitude Data for Horizontal Component Long Period Array Beams with Individual Traces Band Pass Filtered		6	

INTRODUCTION

Long period signals and noise recorded at the seismic arrays UBO, TFO and LASA were analyzed to provide information useful to signal detection efforts and to evaluate the performance of simple long-period beams formed with these arrays. The analysis included the computation of group velocity dispersion for fundamental mode Rayleigh waves generated by seismic events recorded at these arrays, and the calculation of noise reducing properties of beamforming each of the three arrays for a set of twenty five events. All data analyzed in this report were recorded by the arrays UBO, TFO and LASA within the time period June 1, 1969 to December 31, 1969.

RAYLEIGH WAVE GROUP VELOCITY DISPERSION

Knowledge of the Rayleigh group velocity as a function of period for a path, from a specific source area to an array makes it possible to predict accurately the Rayleigh wave arrival time at the array given an event origin time. Alternately it is possible to determine the epicenter location and origin time of an event by using surface wave arrival times at several recording stations and employing the known Rayleigh group velocity dispersion from the source area to each of these stations. The dispersion of Rayleigh wave group velocities is important, therefore, in signal detection, epicenter location, and, used together with other data, in the determination of crustal and upper mantle properties along the path travelled by the surface wave.

The group velocity dispersion for the fundamental mode Rayleigh wave was computed for a set of events. The computations were made by Fourier analysis of the digital data using a moving window technique (Cohen, 1970, and Dziewonski et al, 1969). The source parameters of the events for which dispersion to the arrays was calculated are given in Table I. The actual array instruments which recorded the digital data used in the dispersion calculations are also listed in Table I. No correction was made for the small group delay of the seismograph system.

The calculated Rayleigh fundamental mode dispersion curves are shown in Figures 1 through 20 along with the actual seismograms analyzed. In many cases, these seismograms are of sufficient quality (good signal to noise ratio) to consider them for use as matched filters for other events from the same source areas.

The paths from the source areas to each of the arrays are mixed continental and oceanic for all the events processed. The summary of observed surface wave dispersion presented by Oliver (1962) verifies that the calculated dispersion curves given in Figures 1 through 20 are consistent with previous work in that they do indeed fall within the range bounded by the dispersion curves for pure continental and pure oceanic paths.

ANALYSIS OF ARRAY BEAMS

In forming beams using the long period sensors of the seismic arrays UBO, TFO and LASA, N traces were shifted in time corresponding to a signal group velocity of 3.5 km/sec and then summed. The averages of signal and of noise values for all traces used in forming the beams were computed along with the signal and noise values for the beams. values were calculated by taking one half of the absolute value of the largest peak-to-peak amplitude in the signals. Noise values were determined by calculating the rms amplitude value over a time interval of length ranging from 600 to 800 seconds and selected so that the entire time interval preceded the arrival time of the P phase for the event being processed. The ratio of signal to noise (S/N) in db was then computed for each trace used to make the beam and also for the beam. The S/N improvement in db of the beam over the mean trace S/N was then determined by

For the case of uncorrelated noise, the theoretical improvement is $N^{\frac{1}{2}}$ db.

Beams were formed using the vertical long period instruments of the arrays UBO, TFO and LASA for twenty five different events. The source parameters of these events are listed in Table II. All traces used in forming these beams for UBO, TFO and LASA were first processed through the 15 to 50 second bandpass filter shown in Figure 21.

Signal, noise and signal-to-noise values were then determined for each of the events by the methods previously described. The

results are tabulated in Table III. Mean signal values and S/N values are indicated by the word Mean under the appropriate column headings. The average noise values are listed under the letters rms. For the beams, the signal, noise and S/N values are all listed under the \sum headings. The signal and noise reduction are both given by 20 log $\left(\frac{\sum}{\text{Mean}}\right)$, with \sum and Mean representing signal values in the first case and noise values in the second case.

Each of the events for which UBO, TFO, or LASA beams were formed are presented in Figures 22 through 70. These figures show the actual traces used in formation of the beam and the unphased and phased (beam) traces. The noise traces shown for each event are the entire noise samples used to compute the rms noise values. So that the character of the noise might be more obvious, the noise traces for each event are shown at two magnifications. The trace labeled only with the instrument is at the same gain as the signal trace for that instrument. The trace labeled with the instrument followed by the word NOISE is at an arbitrarily higher gain to show better the noise character.

The mean rms noise levels for UBO, TFO and LASA determined for each event processed are presented in Figure 71. Most noise values for all three of the arrays can be seen to fall within the range of 8 to 20 mµ. The mean noise values higher than 20 mµ can generally be found to have a clearly detectable signal from an event (other than the event being processed) within the noise time sample. Examples of this situation are the Costa Rica, Fox Island, Kermadec Island, Kurile Island, Ryukyu Island, and Sinkiang events.

The reduction of the noise levels at UBO, TFO and LASA by beam formation is shown in Figure 72, and the S/N improvement of the beams for each of the arrays is presented in Figure 73.

In Figures 72 and 73, only those events are included for which 6 or 7 traces were used in the UBO and TFO beams, and 16 or 17 traces were used in the LASA beams.

From Figure 72, it can be seen that the noise reducing properties of UBO and TFO are approximately the same for all the signals processed. The noise reduction of all three arrays for most events processed seems to be within 2 db of the theoretical N^{1/2} for uncorrelated noise. For the Costa Rica and Fox Island events which have a signal in the noise sample, greater noise reduction than the expected $N^{\frac{1}{2}}$ is attained. A fairly large signal in the noise sample can either increase or decrease the noise reducing properties of an array beam, depending on the relative location of the event in the noise sample and the event being processed. For some of the events processed, a slight improvement (less than one db) in the LASA noise reduction properties may be obtained by adjusting the calibration used to convert the digital counts to millimicrons for data from the C1Z and C2Z instruments. These instruments have very low gains and were not calibrated for these gains in forming some of the beams. In these cases C1Z and C2Z are of low amplitude and contribute very little in reducing the noise.

The S/N improvement of the beams of each of the arrays is shown in Figures 73 and 74. From Figure 73, it can be seen that UBO beams using 6 or 7 traces give about the same S/N improvement as LASA beams using 16 or 17 traces for the events presented. In Figure 74, the S/N improvement compared to $N^{\frac{1}{2}}$ for all events processed (having any number of traces) is presented. This figure shows that the UBO and TFO beams perform equally well and that the S/N improvement is usually within 4 db of the $N^{\frac{1}{2}}$ values, while the LASA beams are often more than 3 db below the tweoretical $N^{\frac{1}{2}}$ values.

Loss of signal amplitude in the process of forming beams using a group velocity of 3.5 km/sec seems to be one factor making the LASA beams relatively less effective than the UBO and TFO beams. This observation is confirmed by forming beams using only the AOZ instrument and either the C-ring or the F-ring instruments for group velocities of 3.0 km/sec and 3.8 km/sec (Table IV). Using the C-ring instruments, the diameter of the array is not large enough to show much difference in S/N for the two group velocities. However, there is 3 db difference in the S/N for group velocities of 3.0 and 3.8 km/sec using AOZ and the F-ring instruments. It is apparent, therefore, that care should be taken in the selection of the group velocity with which to beam a large aperture long period array.

Long period beams were formed using a low-pass filter (Figure 21) on the vertical components for events recorded at UBO and TFO. The results are presented in Table V. Comparing the data in Table V with that in Table III, it can be seen that the band-pass filter eliminated approximately the same amount of noise as did the low-pass filter.

Beams formed using band-passed horizontal traces for UBO and TFO (Table VI) show that these horizontal beams are as efficient as the vertical component beams. The noise reduction for any one event recorded at any array are approximately the same for both the horizontal components.

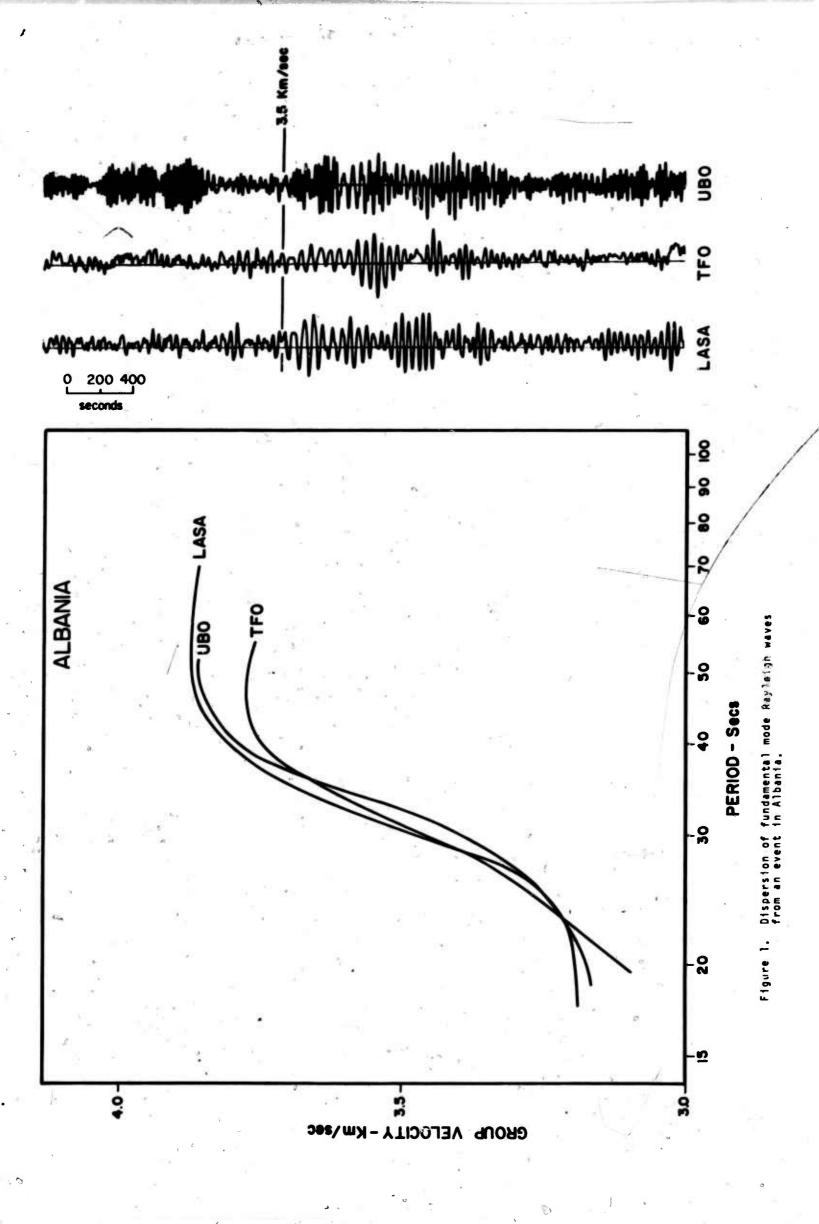
CONCLUSIONS

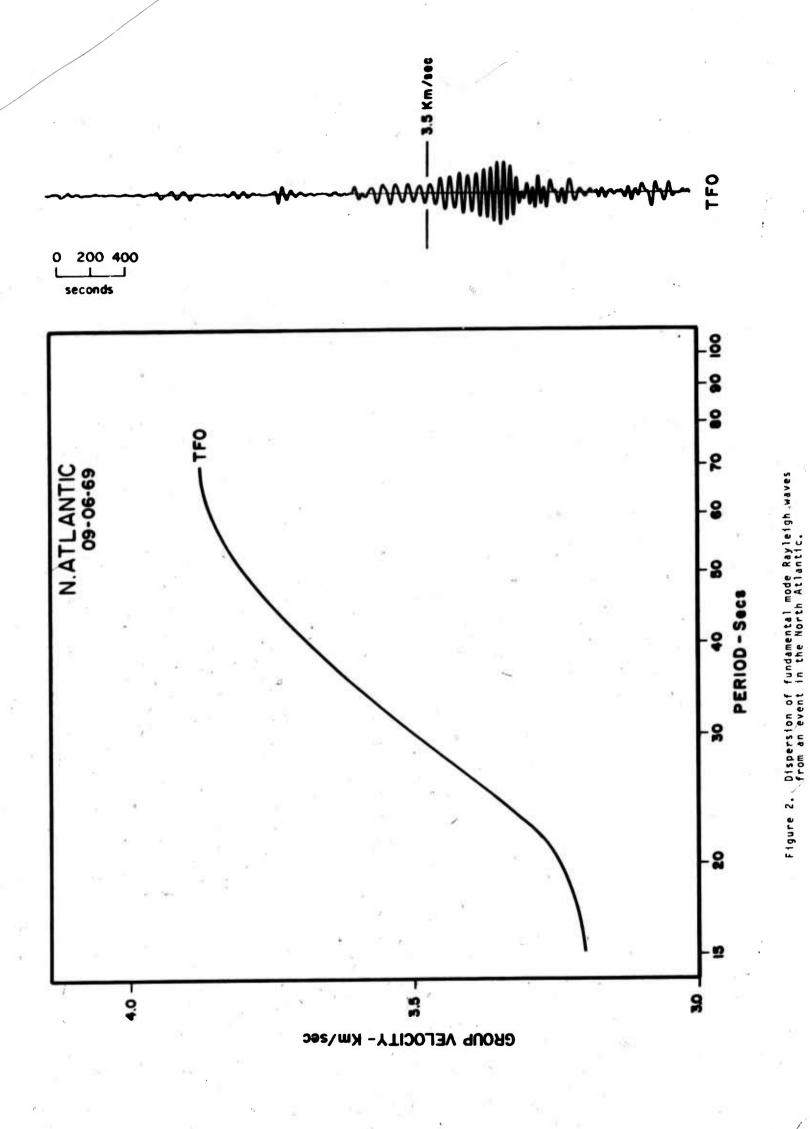
Utilization of the long period signals assembled and the fundamental Rayleigh mode dispersion curves calculated in this study should increase the effectiveness of the arrays UBO, TFO and LASA as detectors of energy from seismic events.

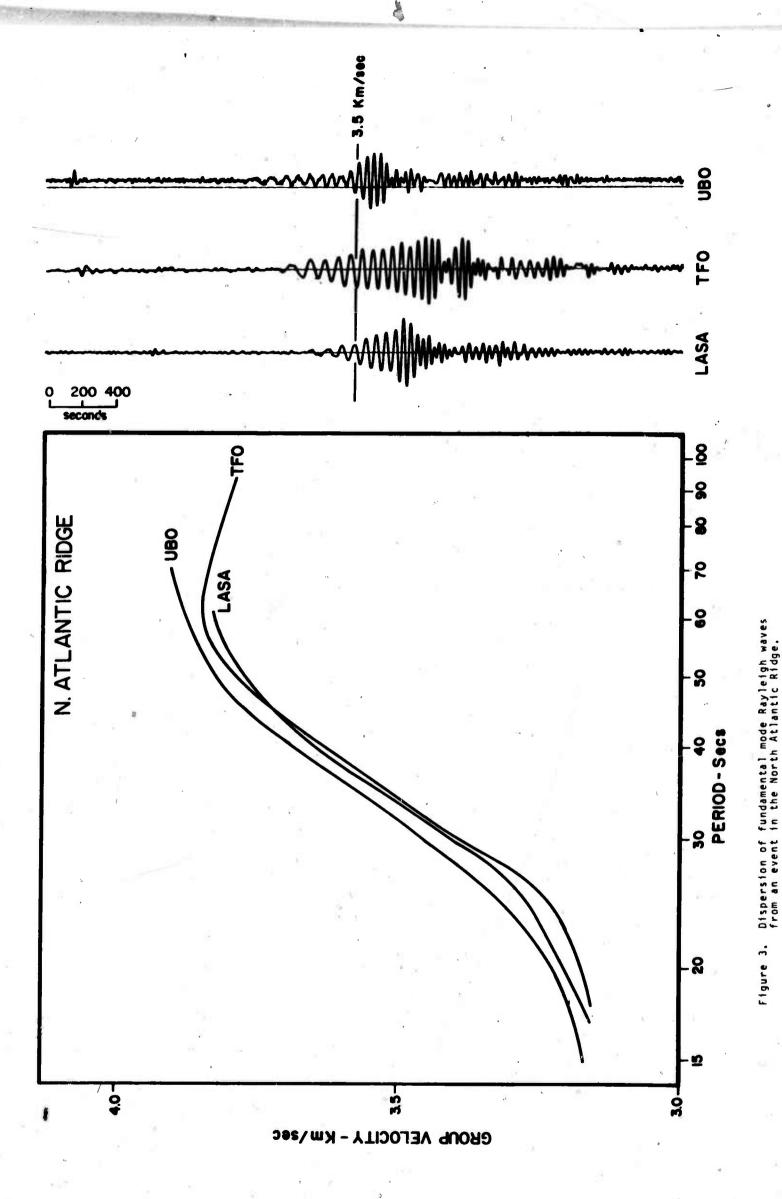
The rms noise level seems to be in the 8 to 20 mµ range for each of the arrays UBO, TFO and LASA. The reduction of noise through simple beamforming approaches the value of $N^{\frac{1}{2}}$ db for each of the three arrays. Signal loss is incurred, however, in beaming LASA with a group velocity of 3.5 km/sec for all events.

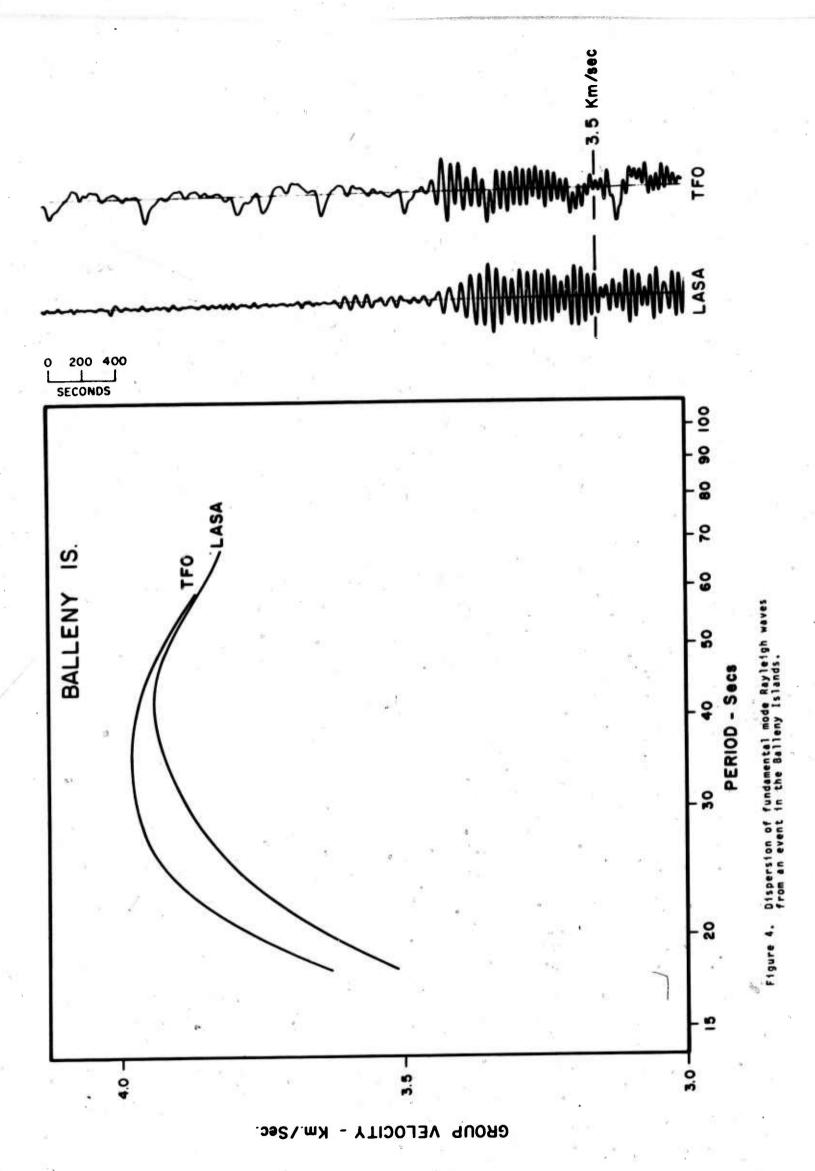
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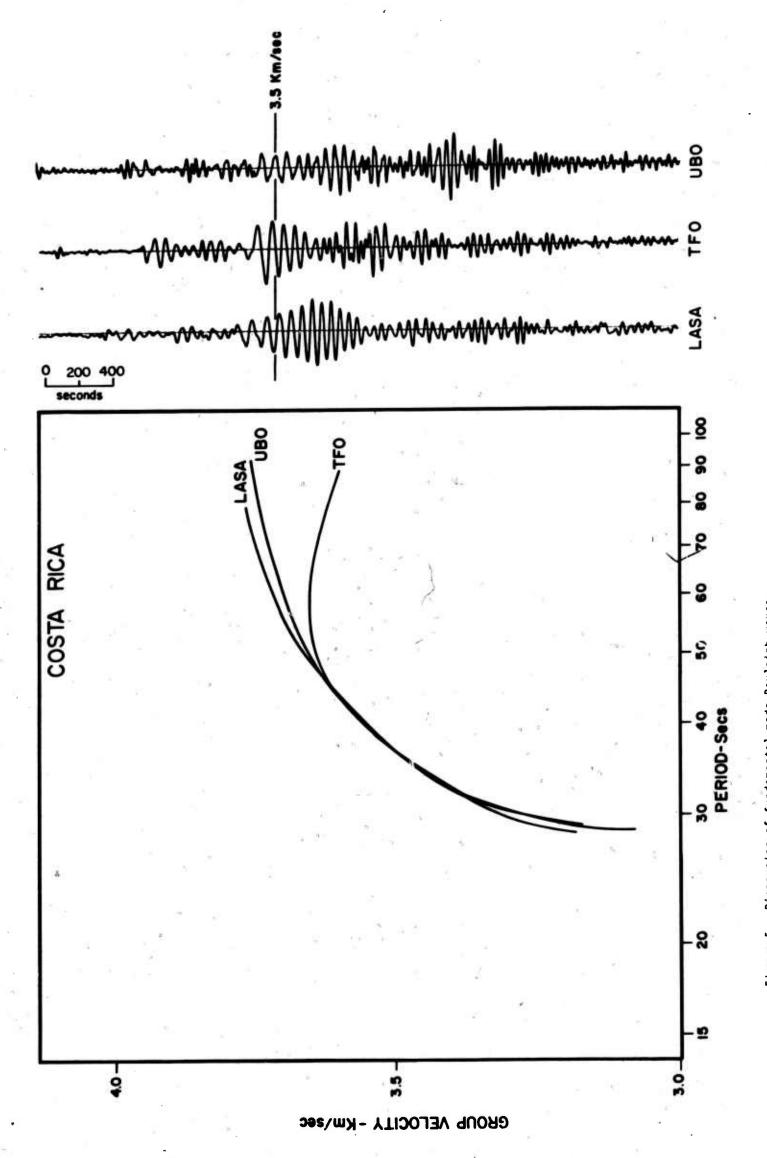


Figure 5. Dispersion of fundamental mode Rayleigh waves from an event in Costa Rica.

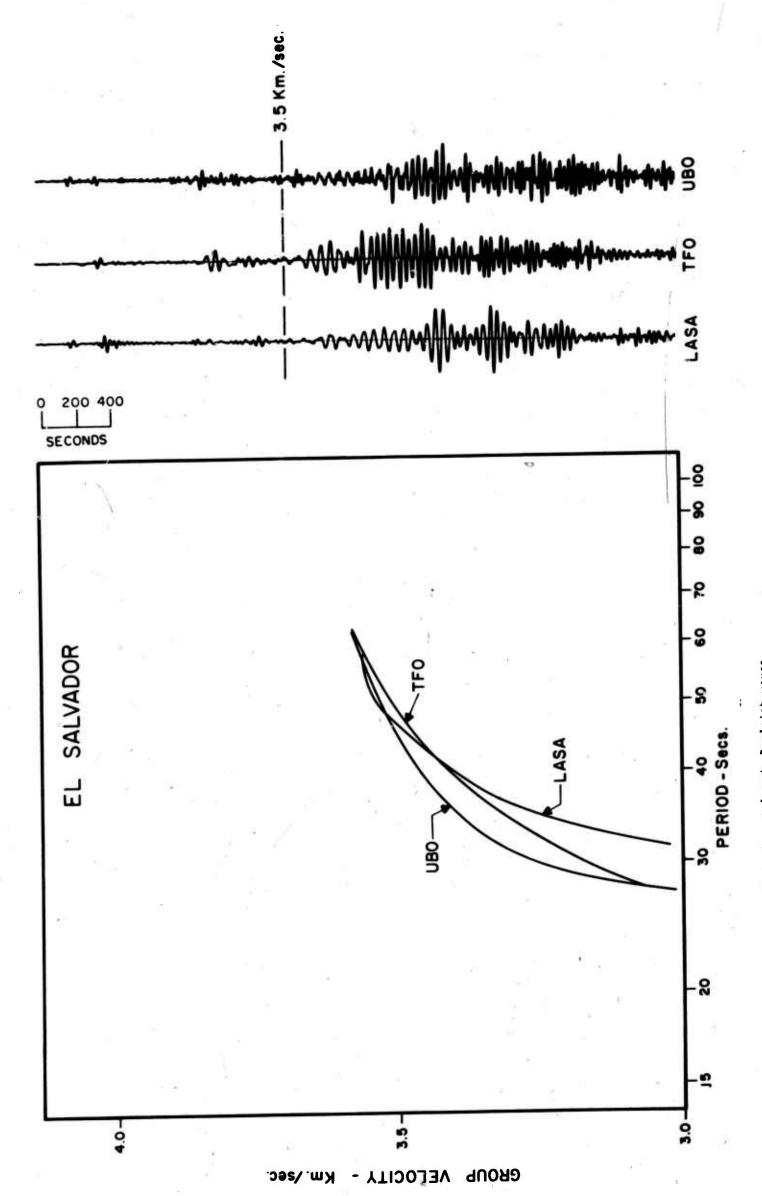
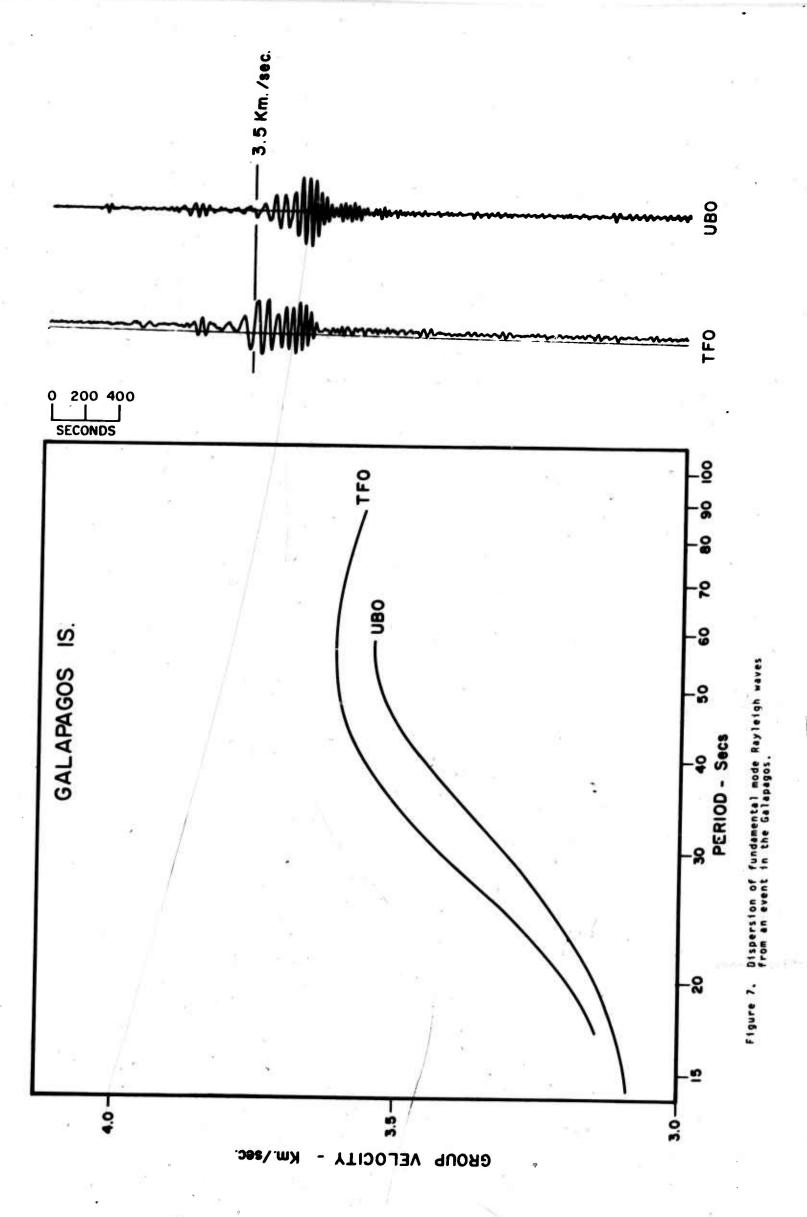
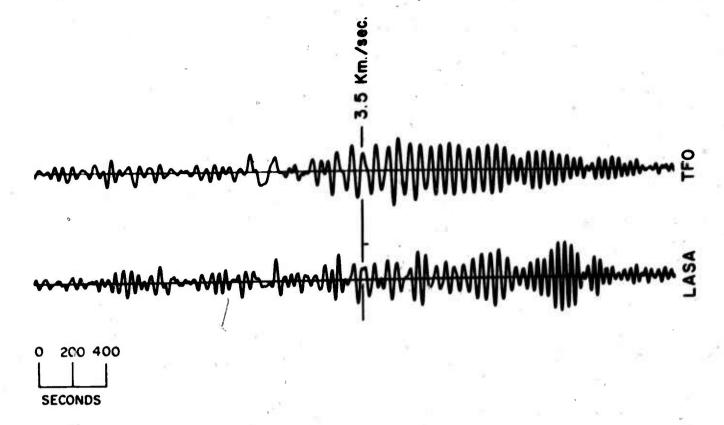


Figure 6. Dispersion of fundamental mode Rayleigh waves . from an event in El Salvador.





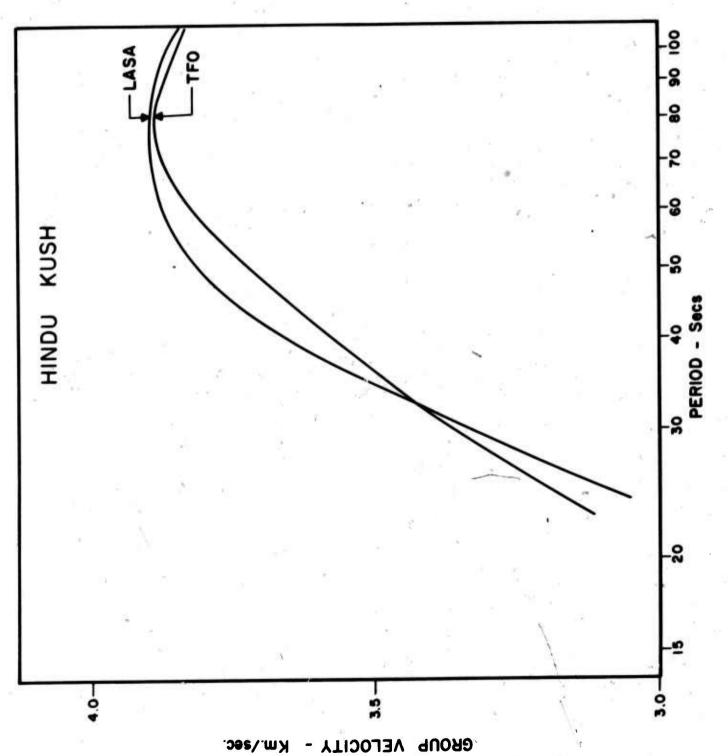
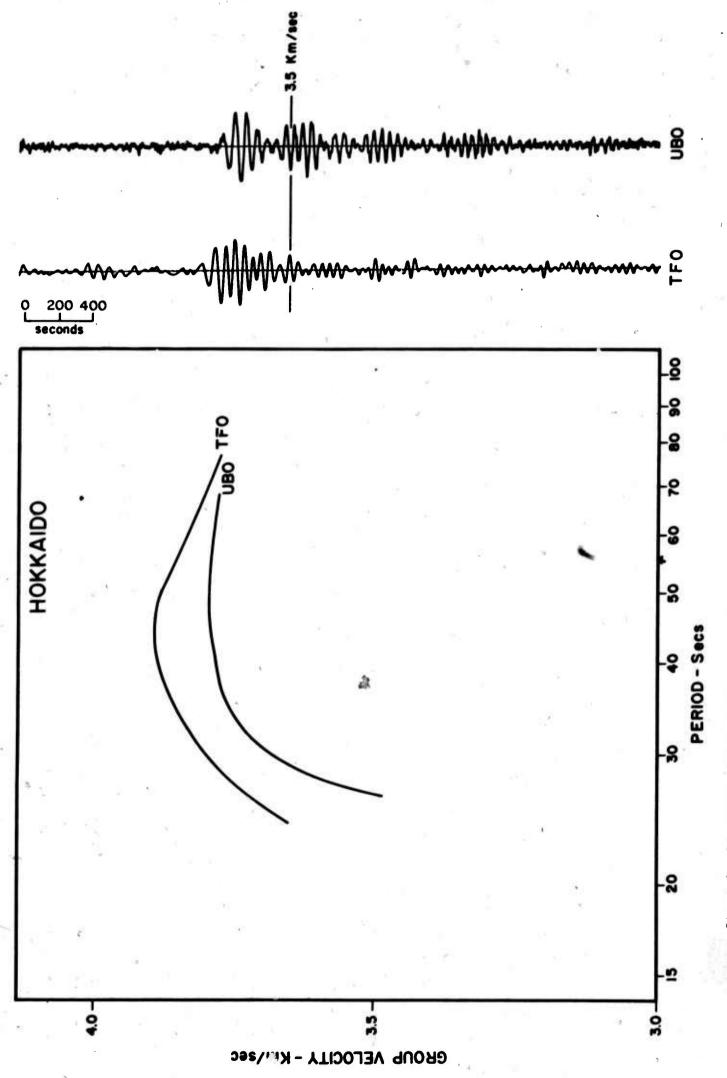


Figure 8. Dispersion of fundamental mode Rayleigh waves from an event in Hindu Kush.



ure.9. Dispersion of fundamental mode Rayleigh waves from an event in Hokkaido.

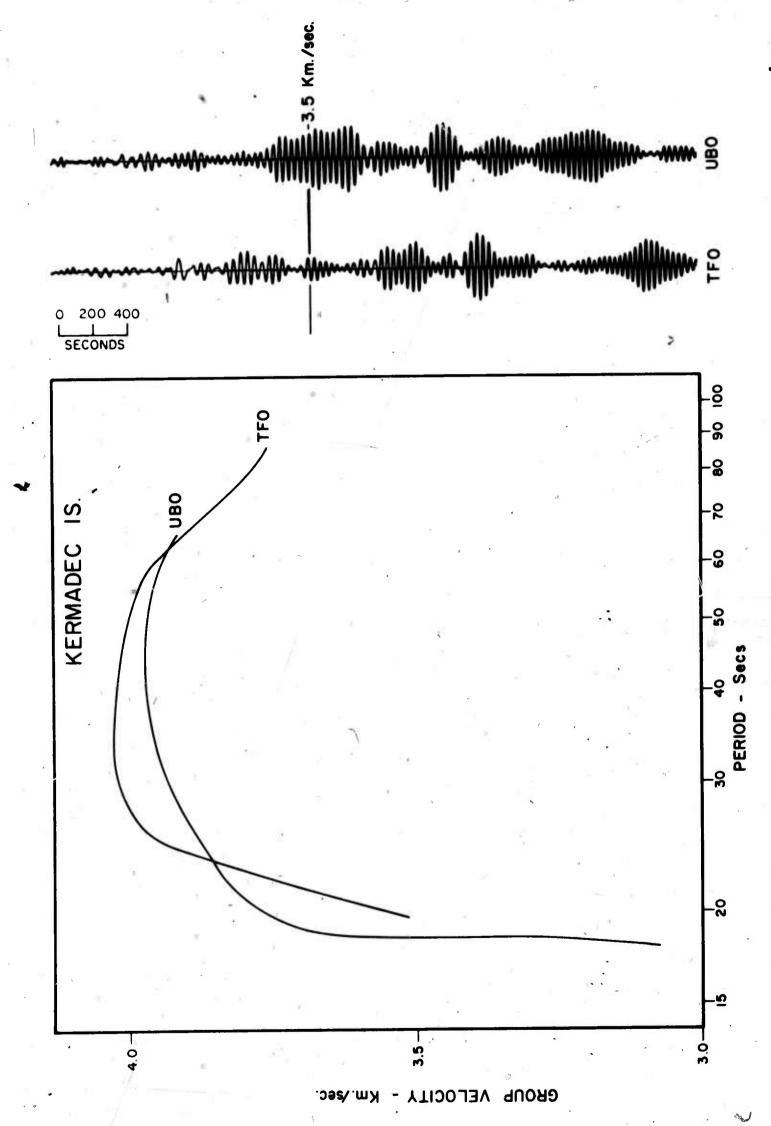
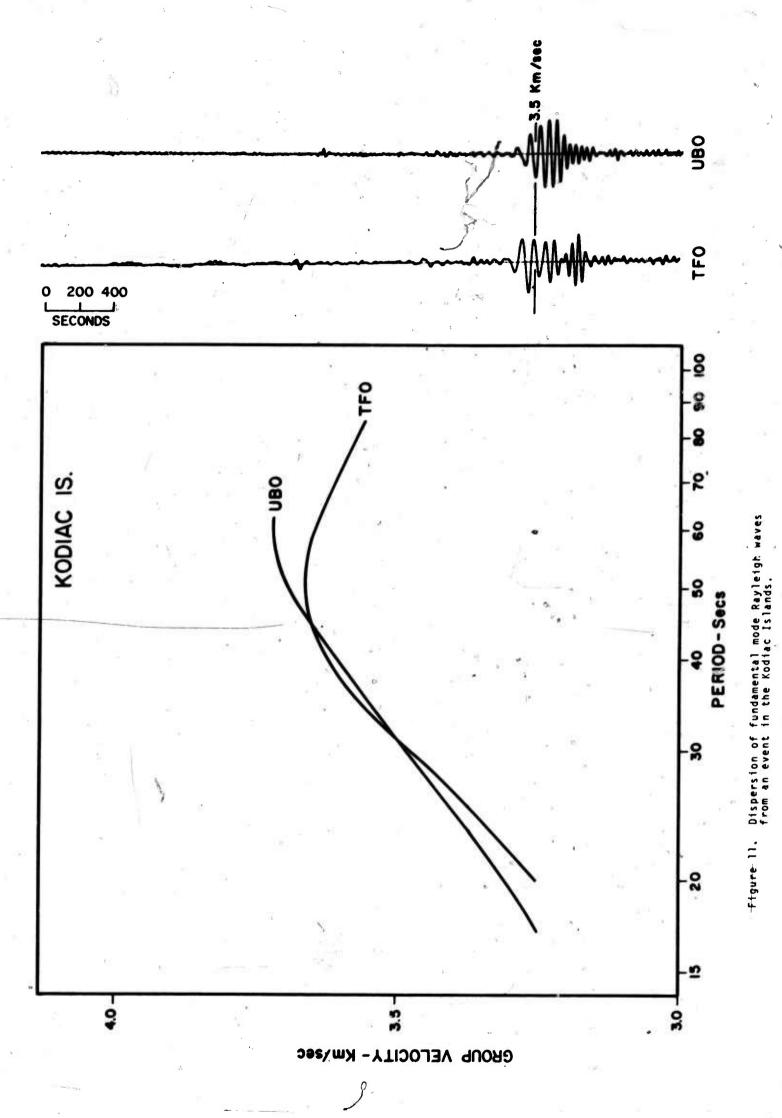
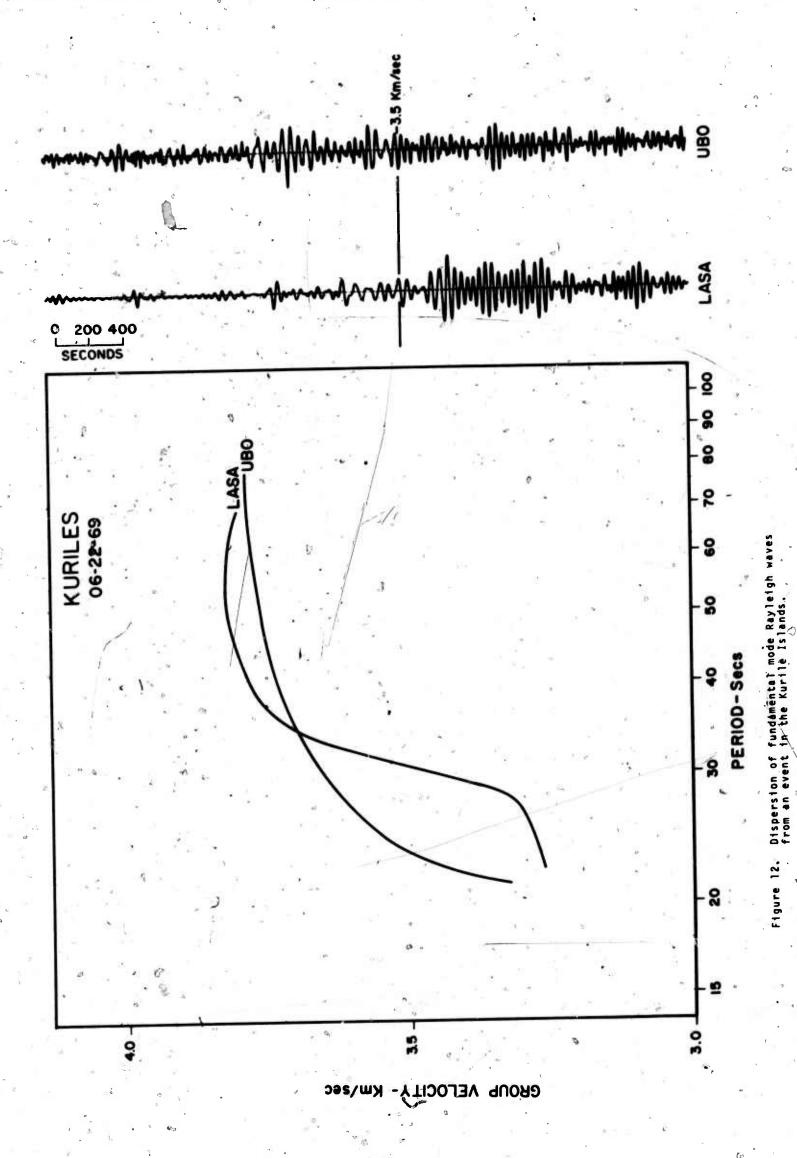
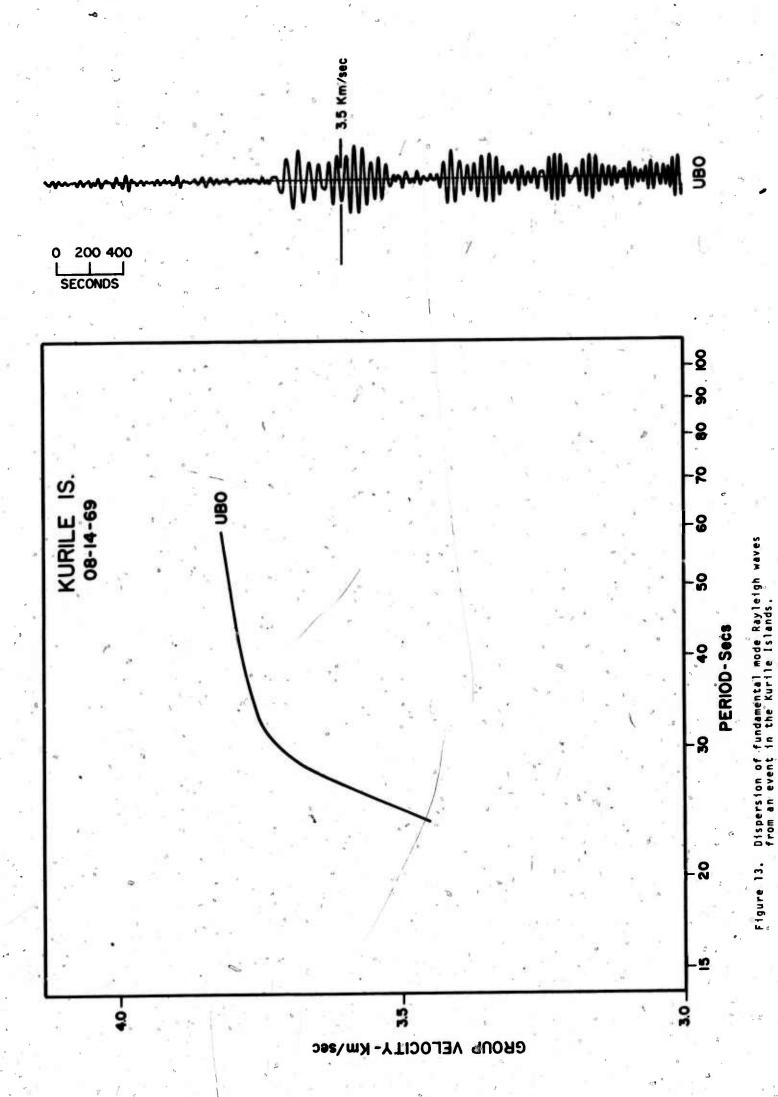
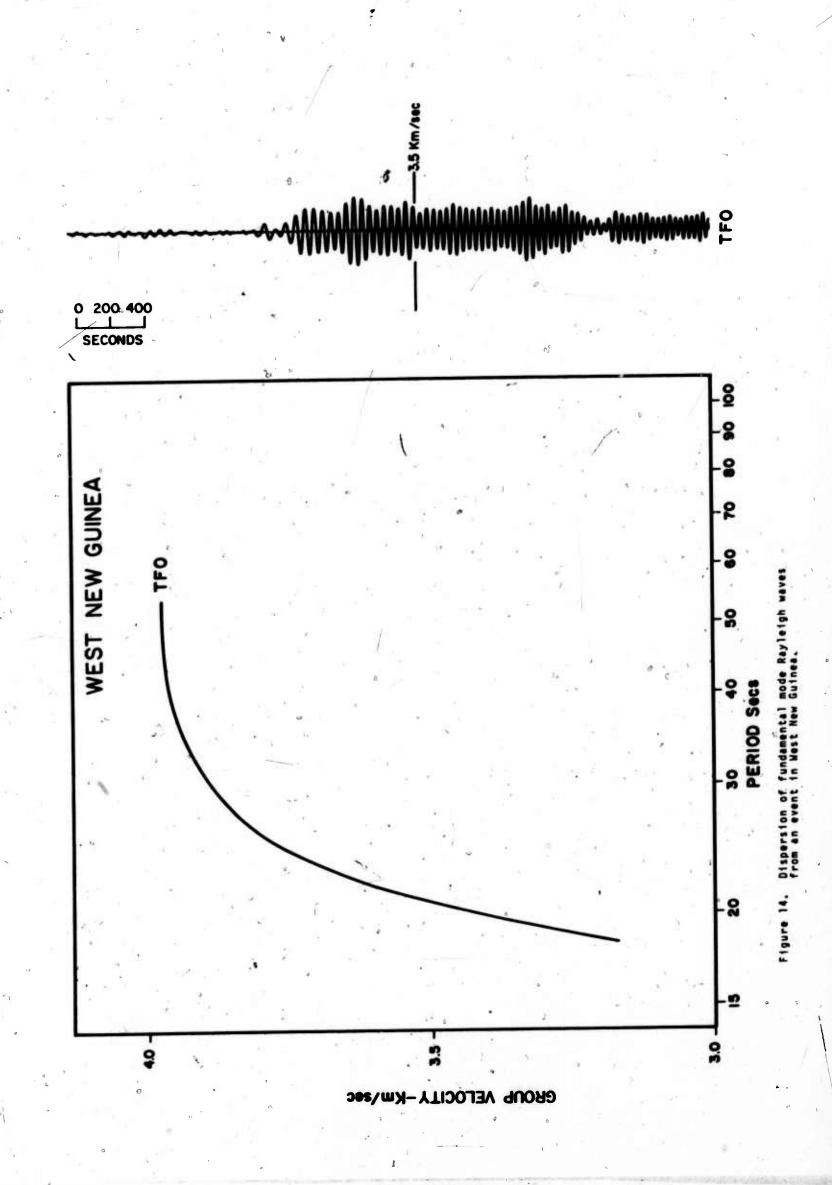


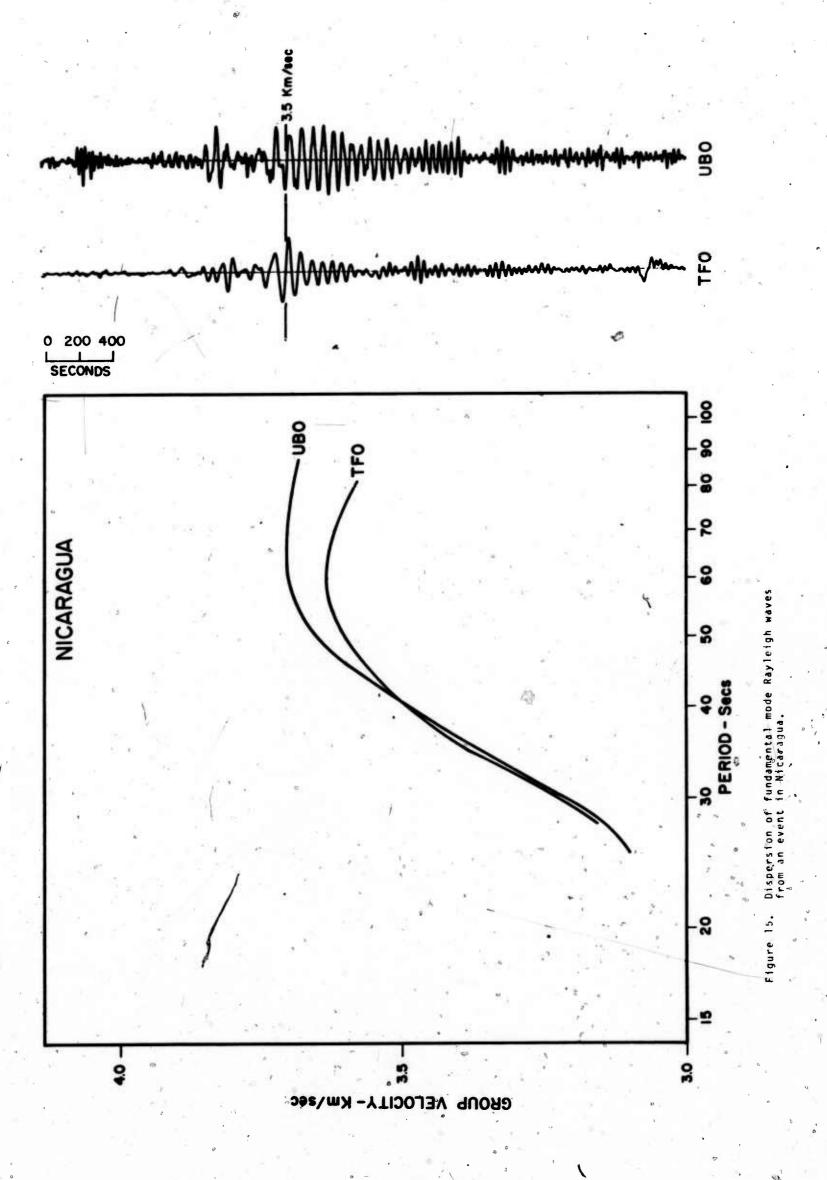
Figure 10. Dispersion of fundamental mode Rayleigh waves from an event in the Kermadec Islands.











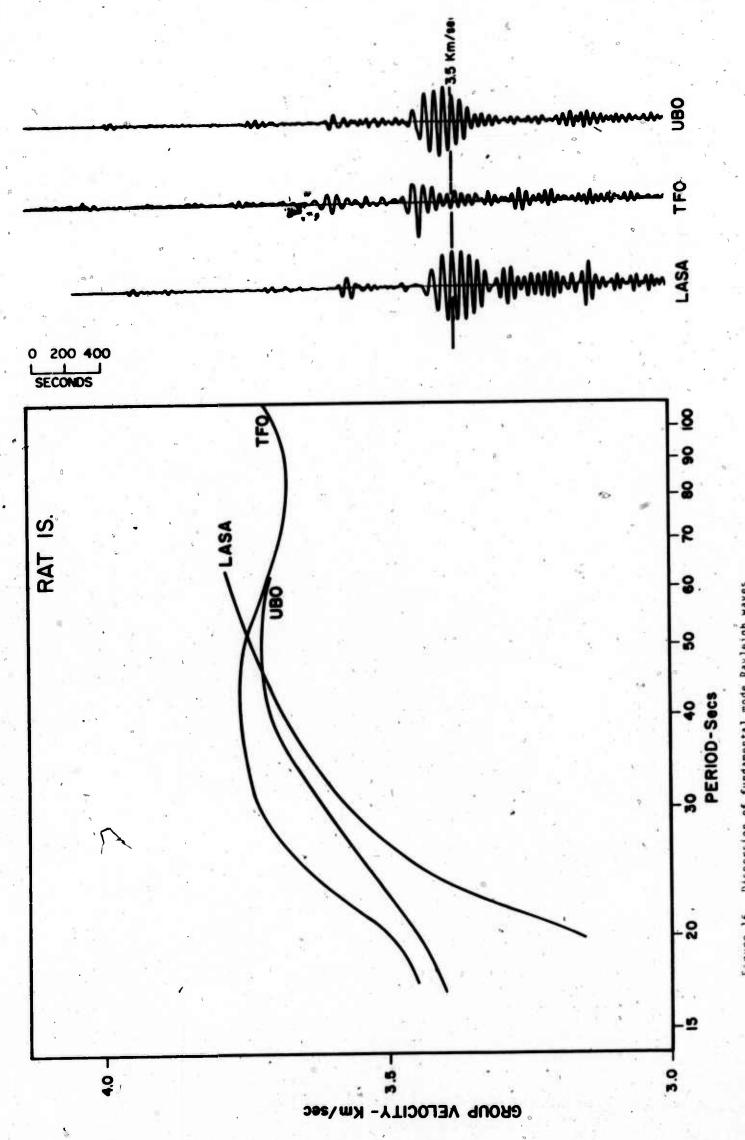
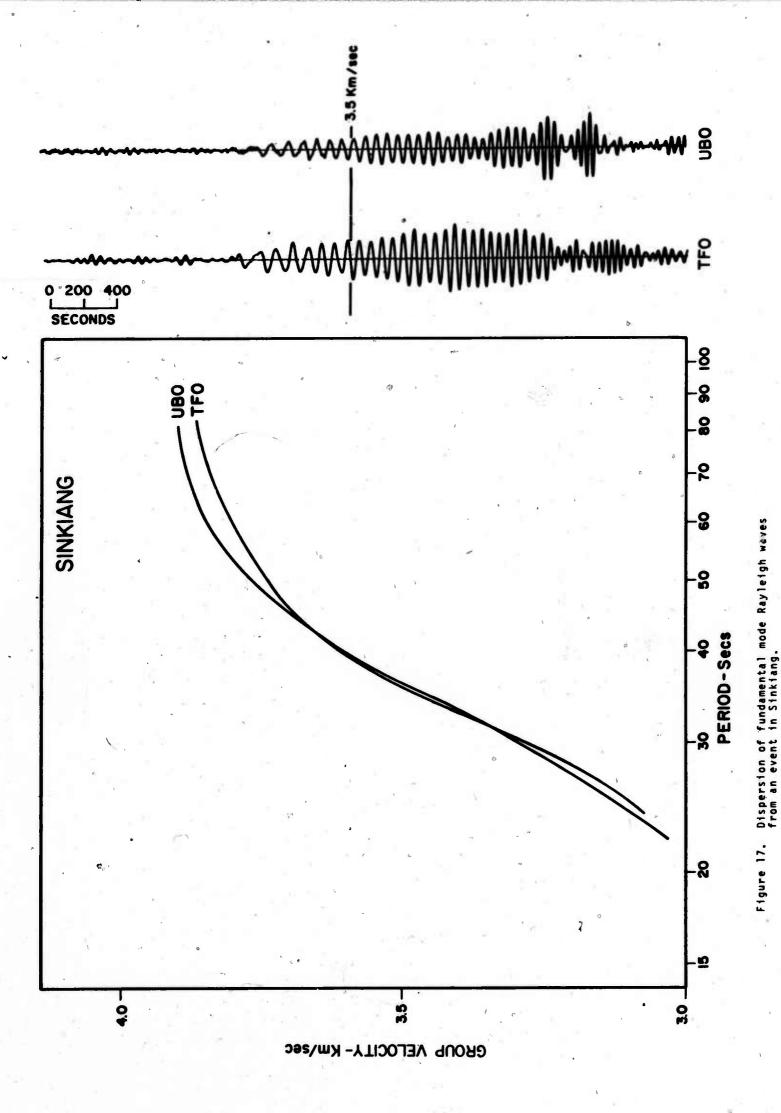
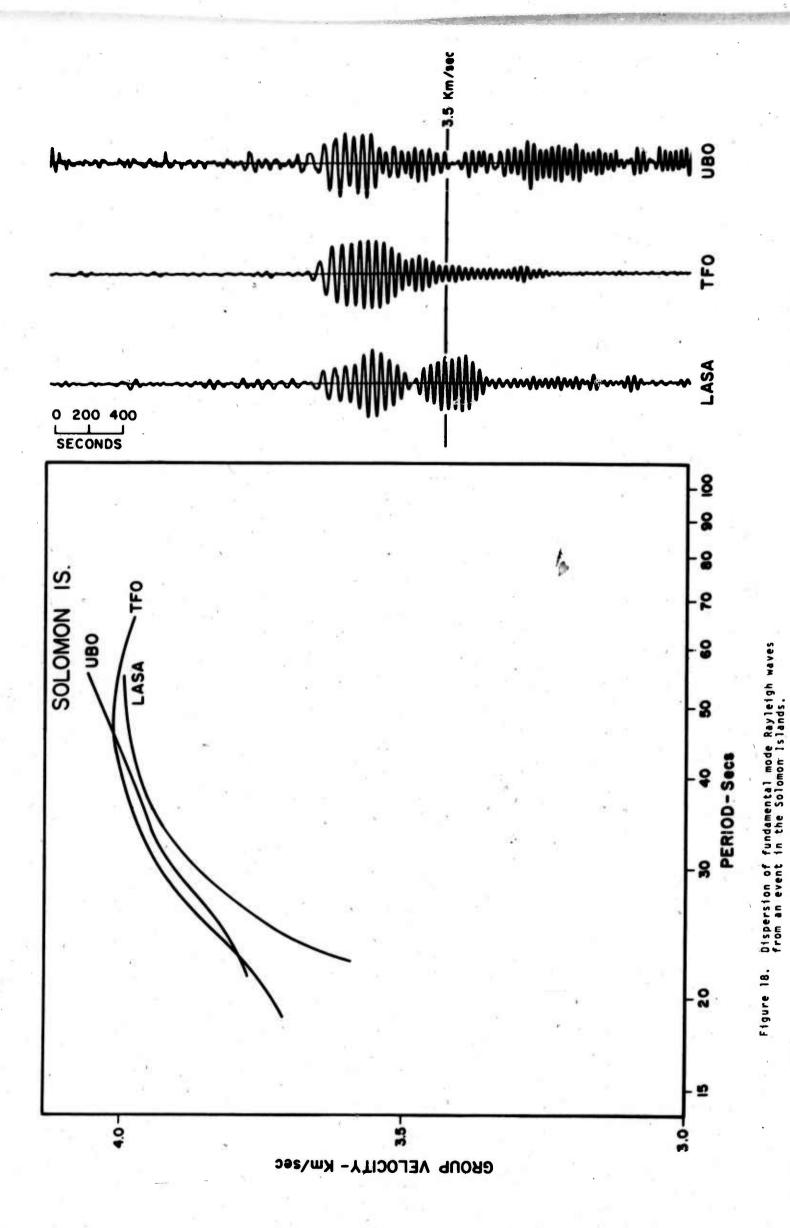
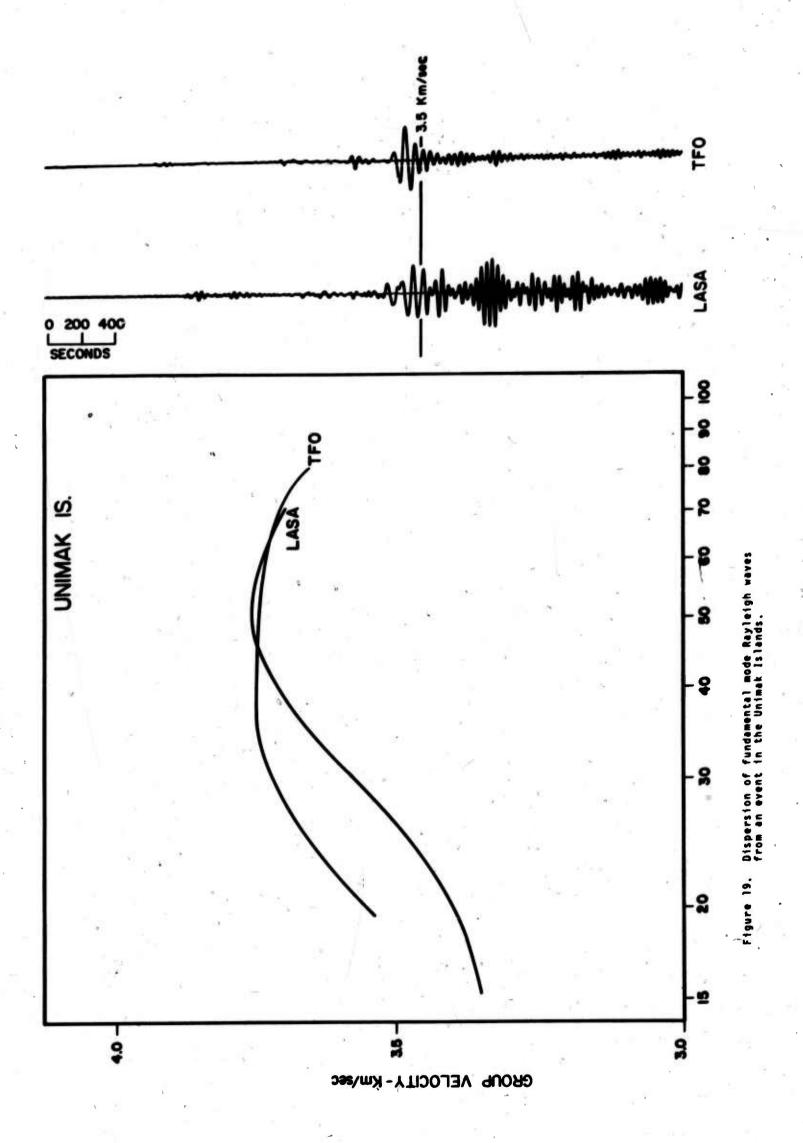


Figure 16. Dispersion of fundamental mode Rayleigh waves from an event in the Rat Islands.







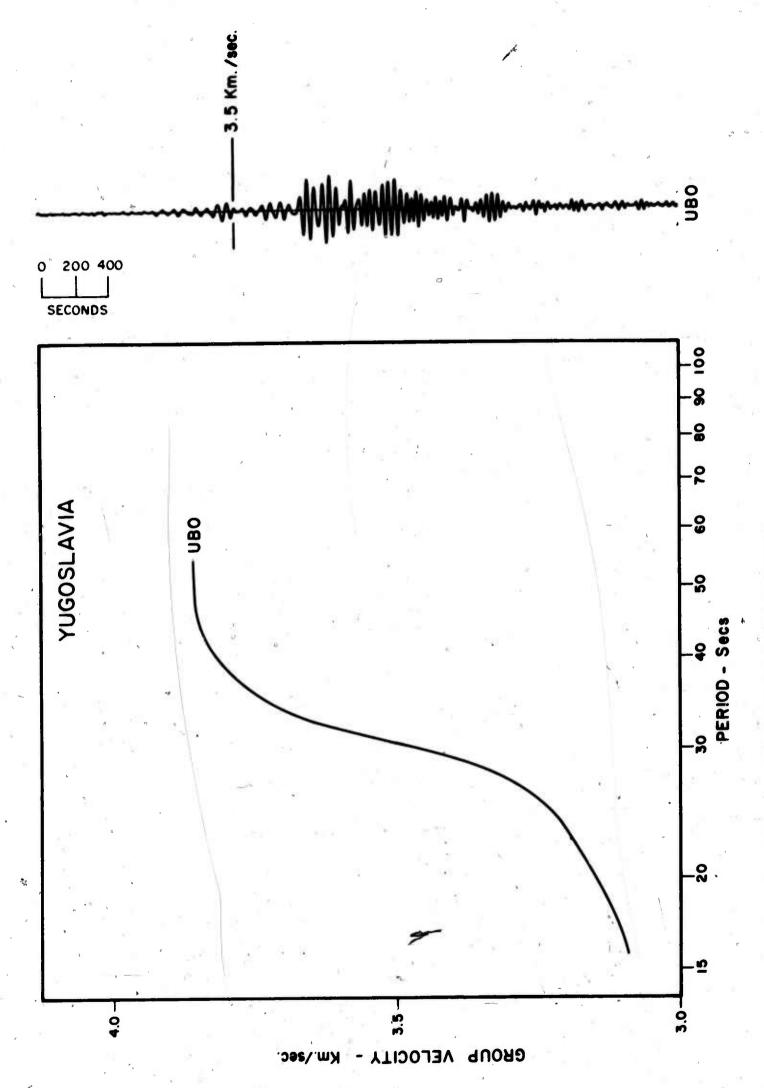


Figure 20. Dispersion of fundamental mode Rayleigh waves from an event in Yugoslavia.

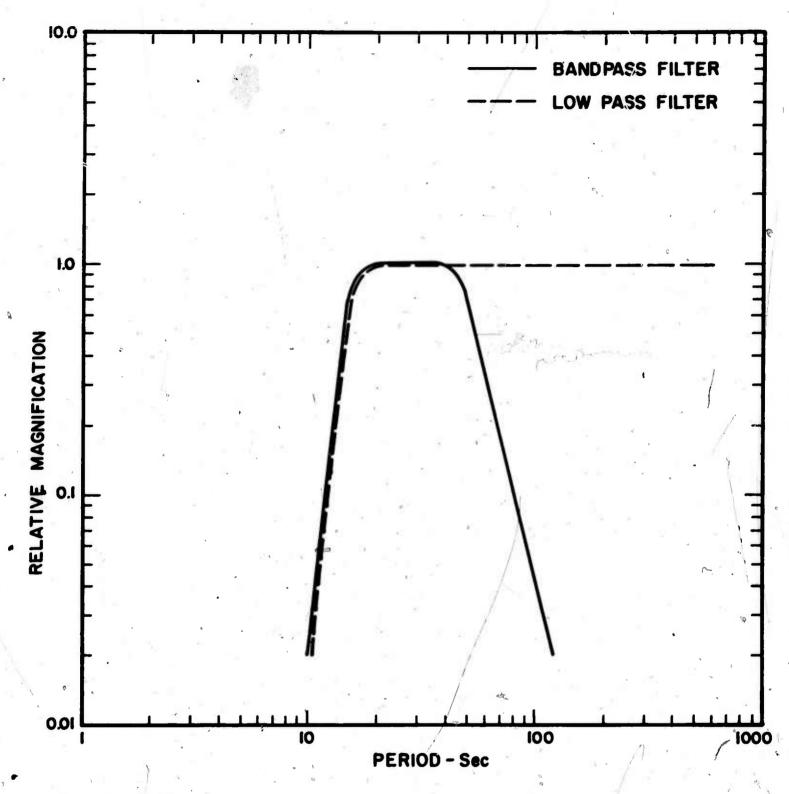
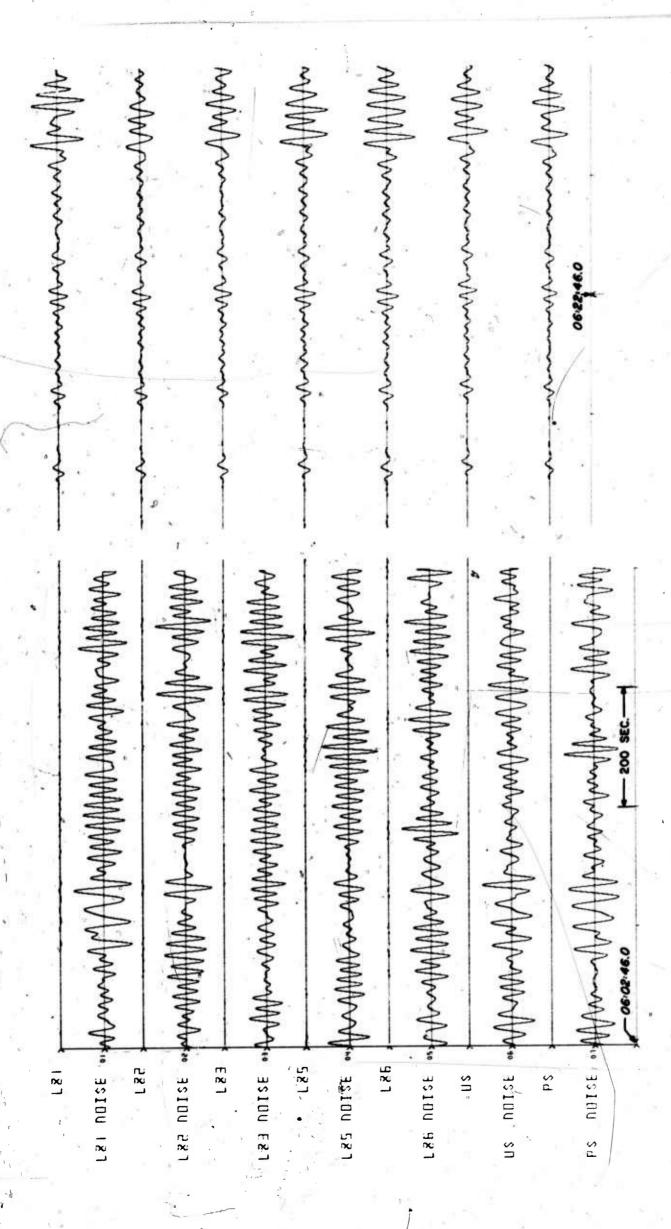


Figure 21. Low pass and band pass filters used in long period data processing.

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jure 22. Band pass filtered noise and signal traces with unphased and phased sums for an event in Albania recorded at UBO.



an event in Argentina filtered noise and signal traces with and phased sums for an event in Argent unphased and phased sums recorded at UBO. Band pass Figure 23.

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Figure 24. Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic recorded at UBO.

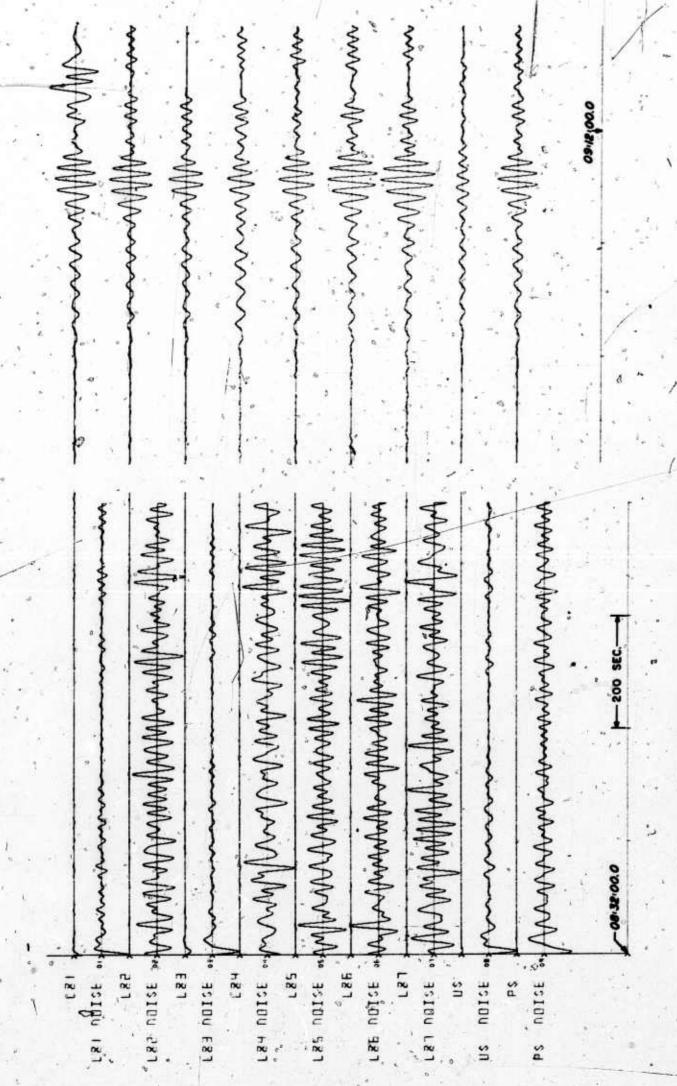


Figure 25. Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic Ridge recorded at UBO.

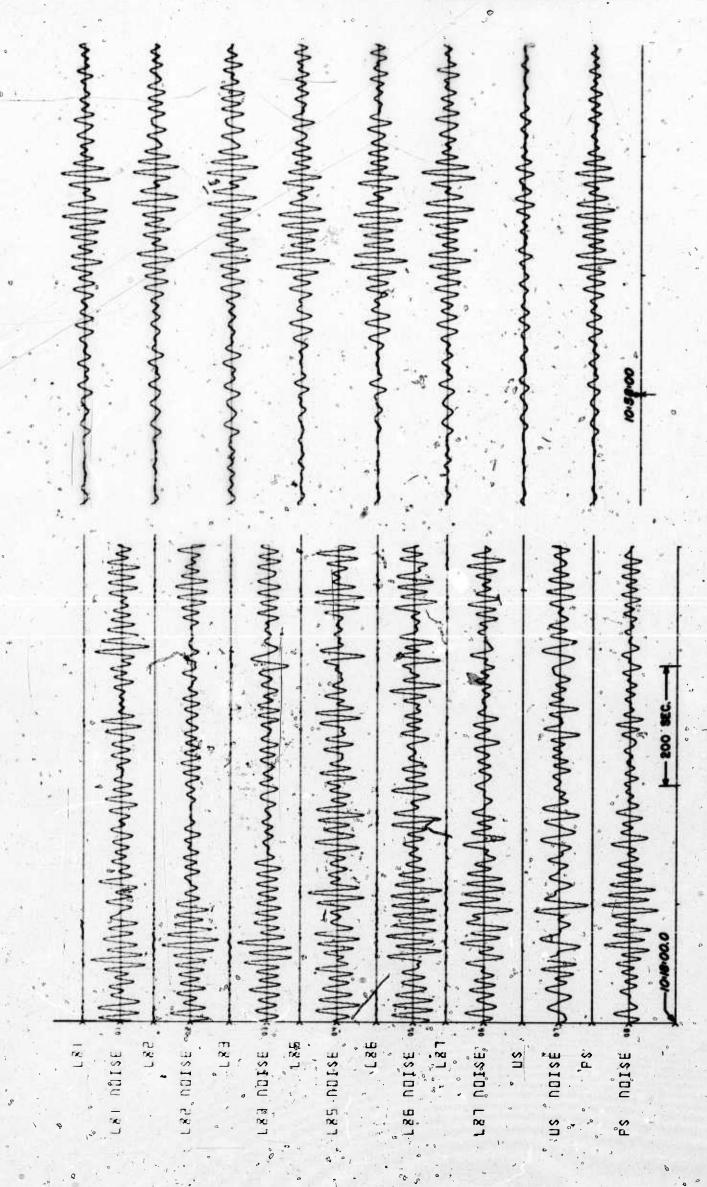


Figure 26. Band pass filtered noise and signal traces with unphased and phased sums for an event at the Coast of Chile recorded at UBO.

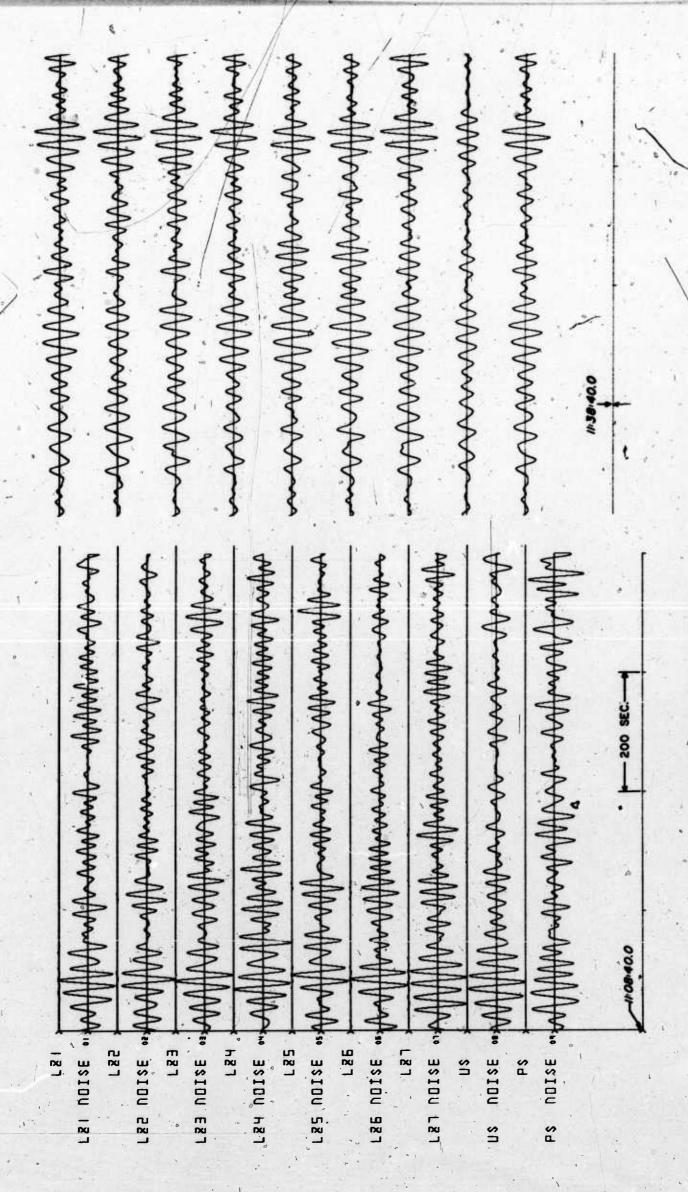


Figure 27. Band pass filtered noise and signal traces with unphased and phased sums for an event in Costa Rica recorded at UBO.

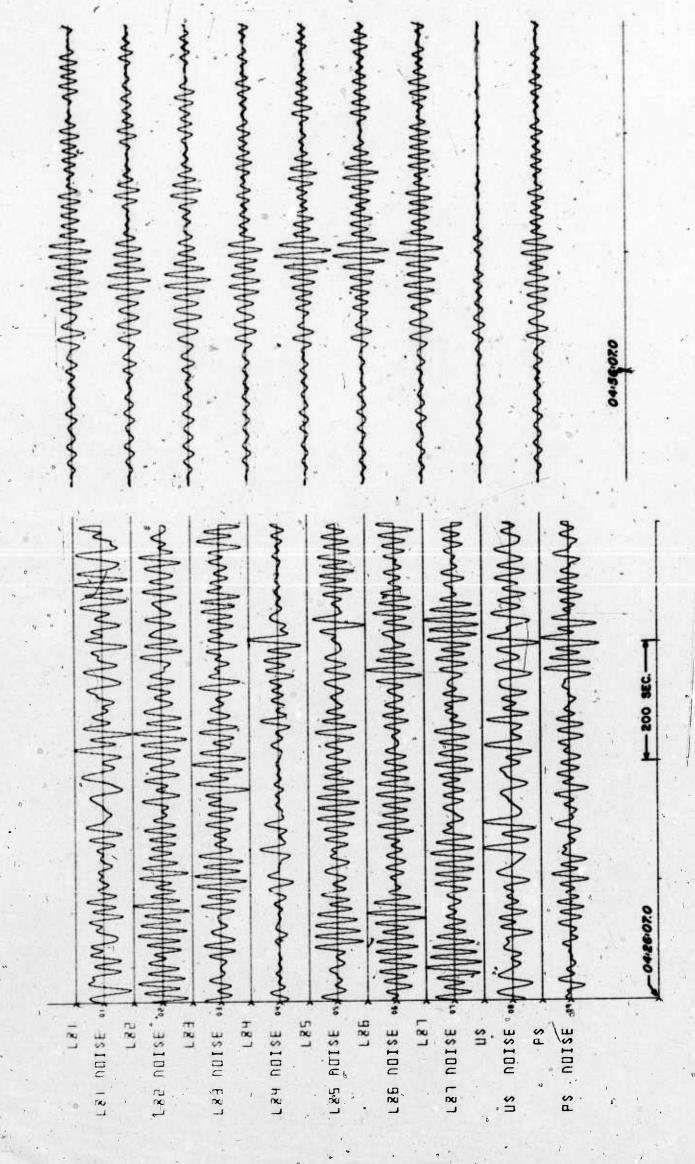


Figure 28. Band pass filtered noise and signal traces with unphased and phased sums for an event in El Salvador recorded at UBO.

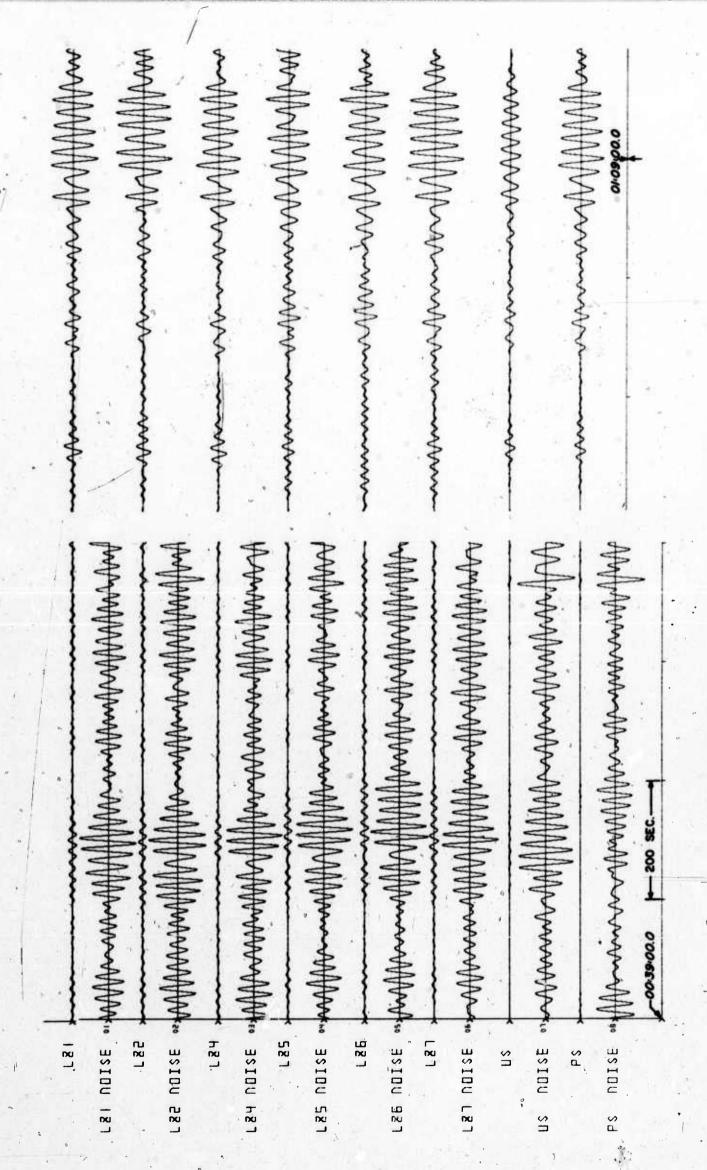


Figure 29. Band pass filtered noise and signal traces with unphased and phased sum for an event in the Fox Islands recorded at UBO.

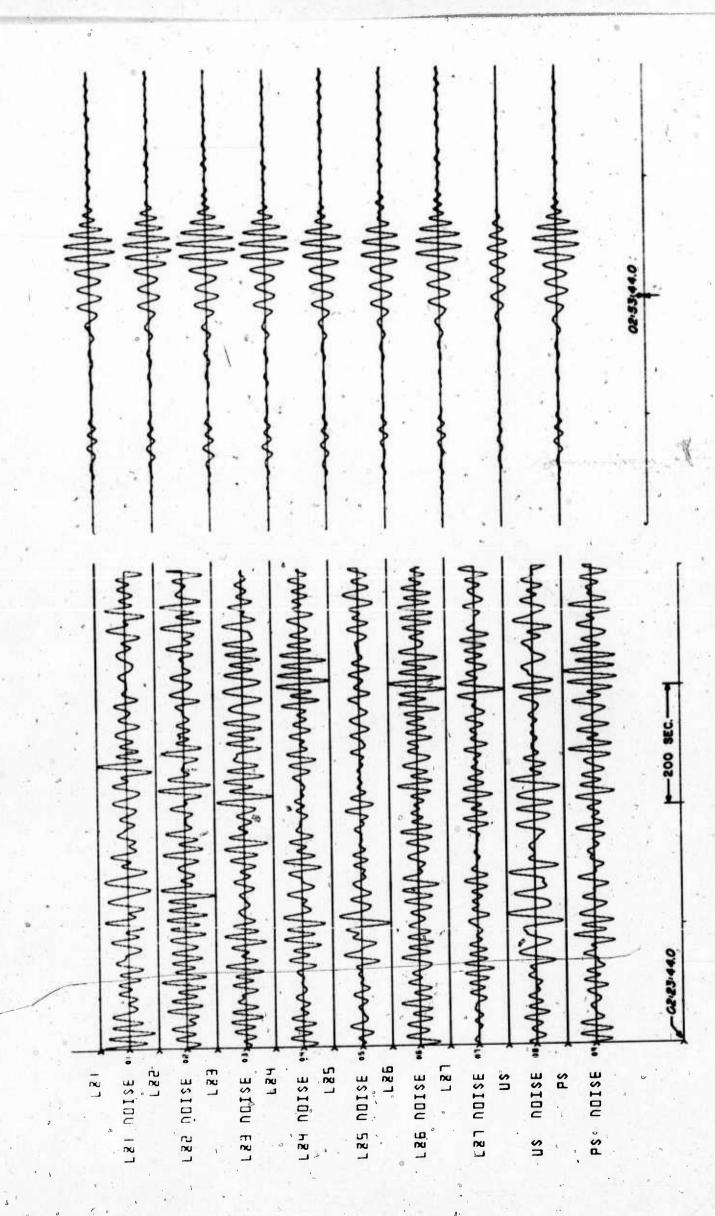
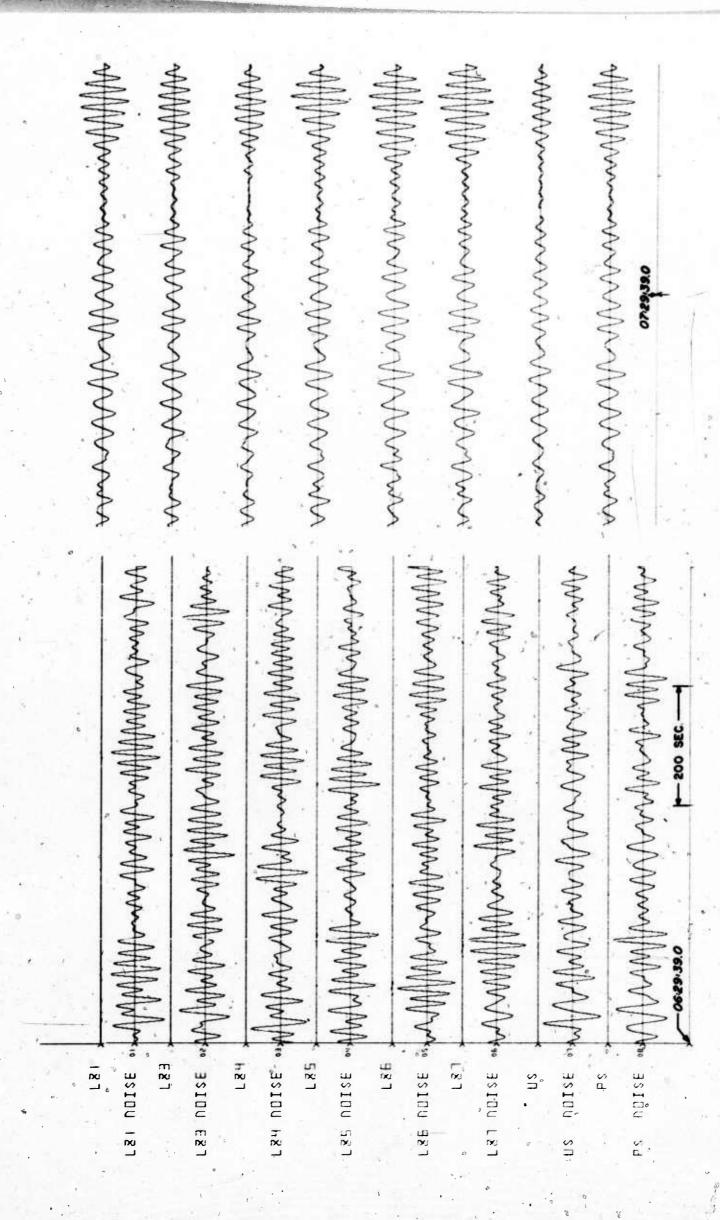
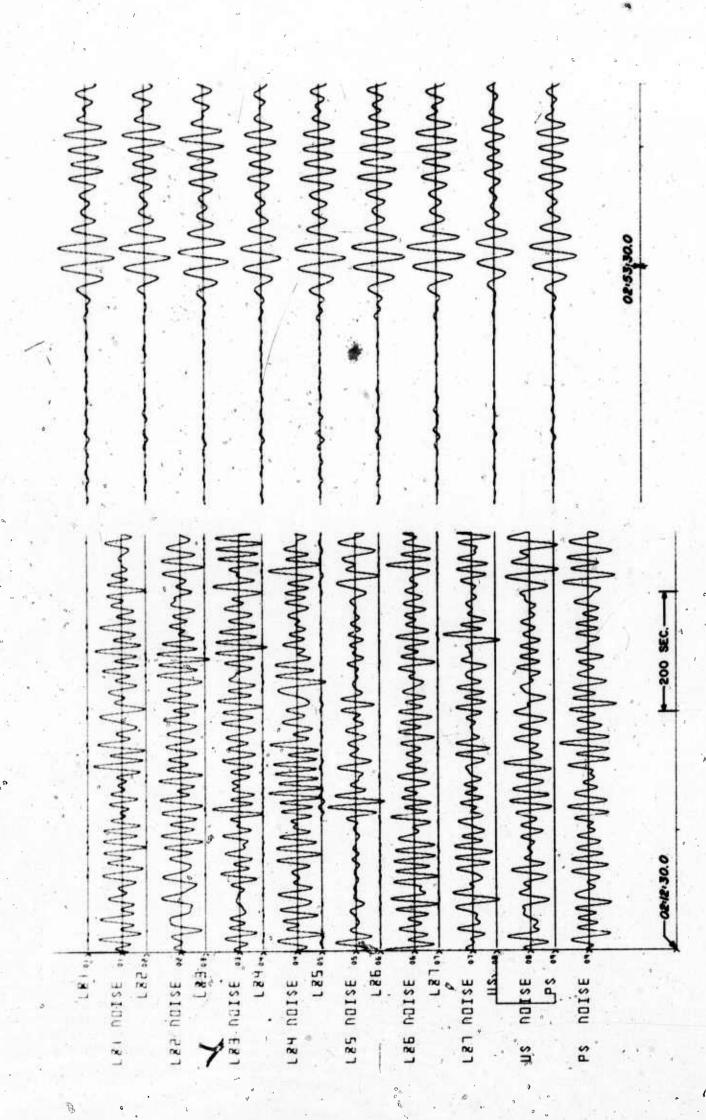


Figure 30. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Galapagos recorded at UBO.



igure 31. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Hindu Kush recorded at UBO.



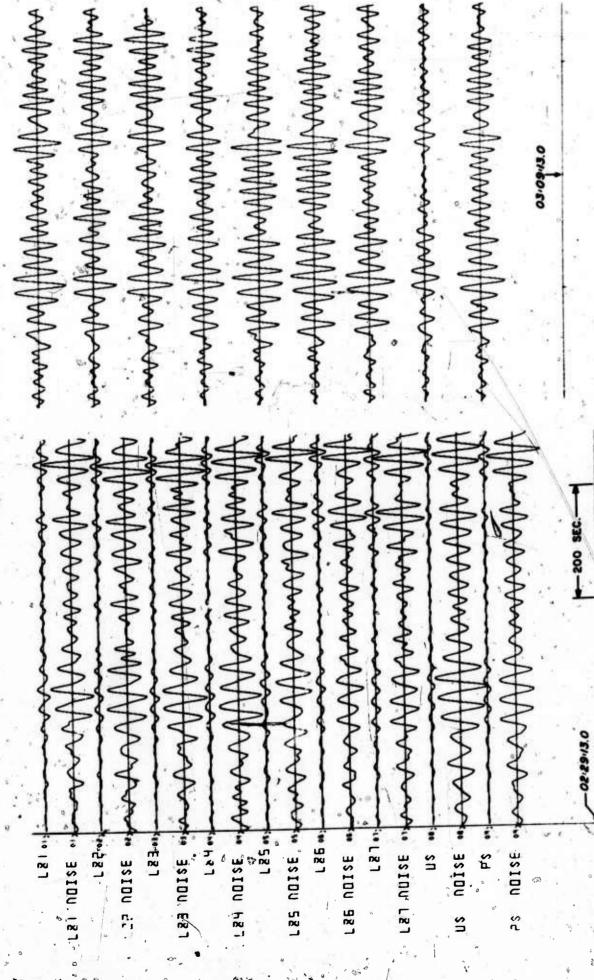
signal traces with an event in Hokkaido and unphased and phased sums Band pass filtered noise recorded at UBO. Figure 32.

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Figure 33. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kermadec Islands recorded at UBO.

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Figure 34. Band pass filtered notice and signal traces with unphased and phased sums for an event in the Kodiac Islands recorded at UBO.



Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kuril Islands recorded at UBO. Figure 35.

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ure 36. Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinea recorded at UBO.

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and signal traces with for an event in Nicaragua Band pass filtered noise unphased and phased sums recorded at UBO. Figure 37.

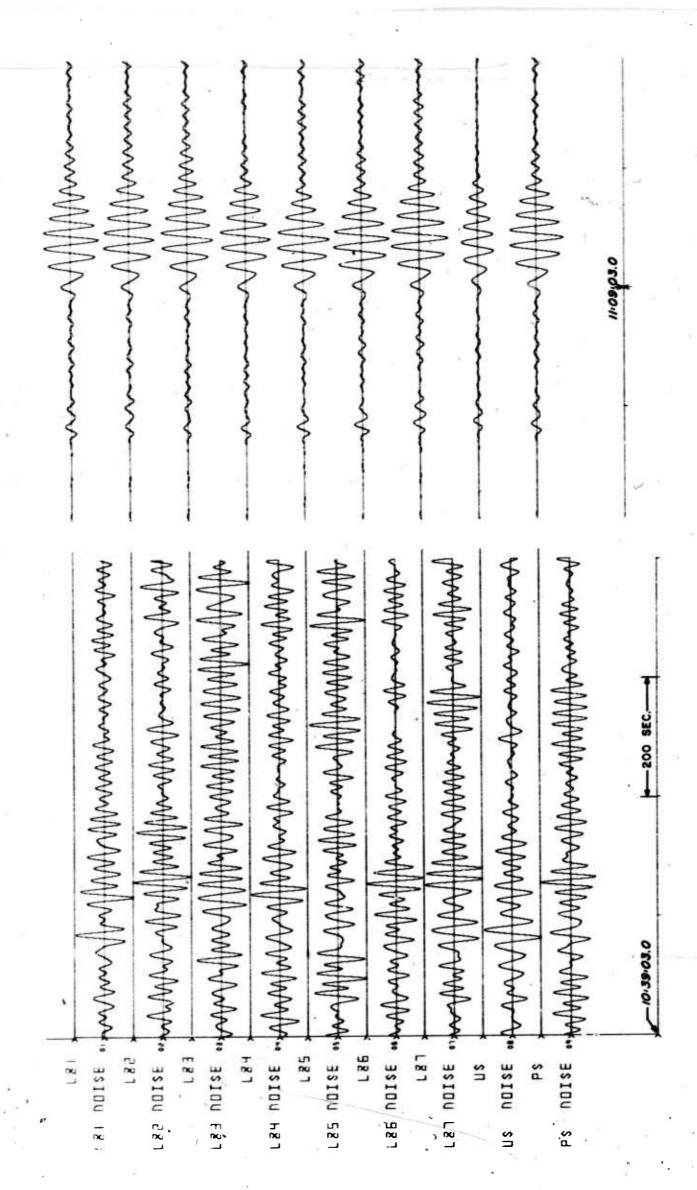
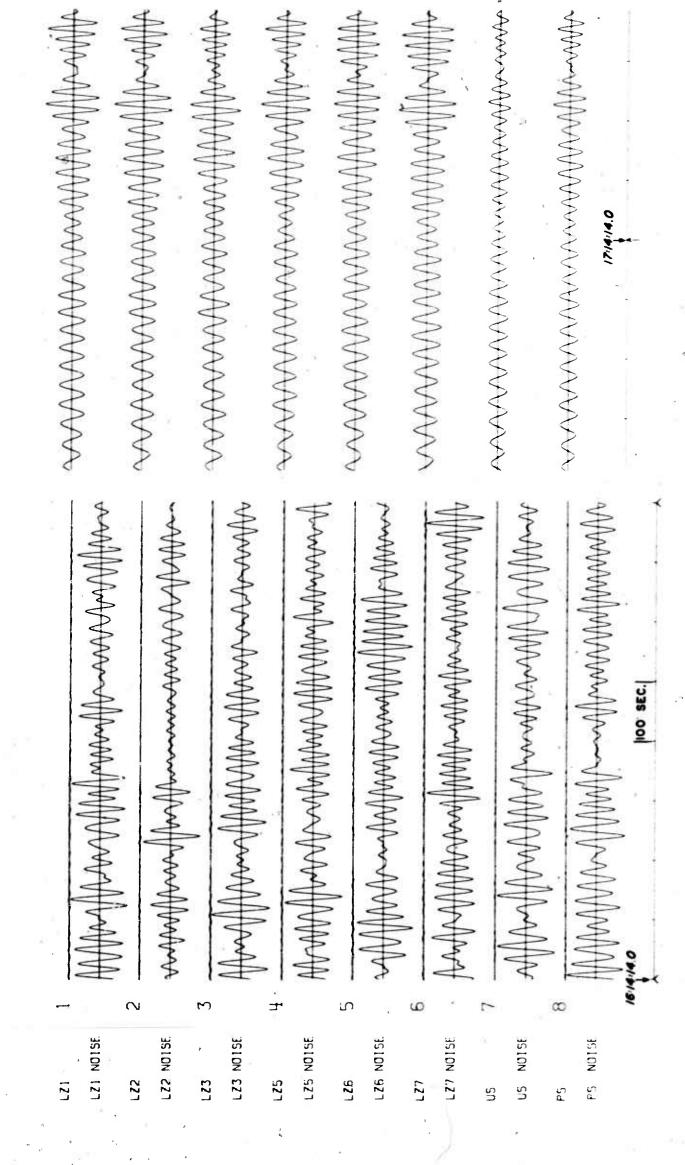


Figure 38. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Rat Islands recorded at UBO.



igure 39. Band pass filtered noise and signal traces with unphased and phased sums for an event in Sinkiang recorded at UBO.

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ire 40. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Volcano Islands recorded at UBO.

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Figure 41. Band pass filtered noise and signal traces with unphased and phased sums for an event in Albania recorded at TFO.

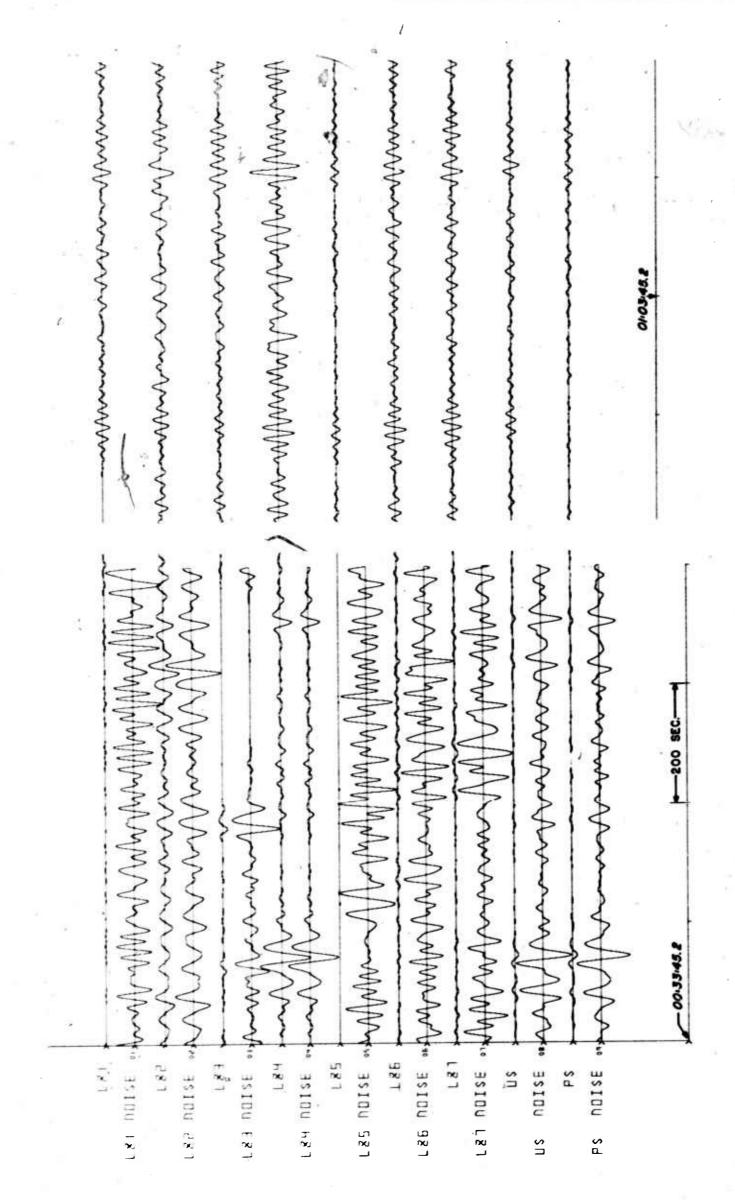
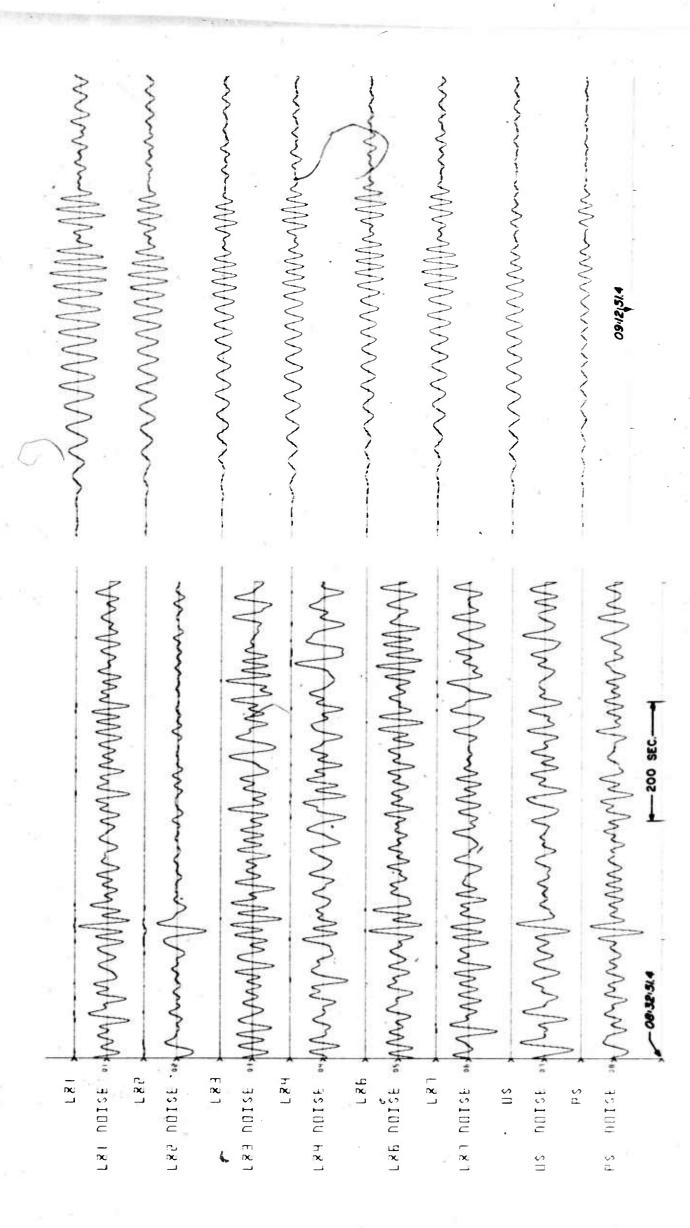


Figure 42. Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic recorded at TFO.



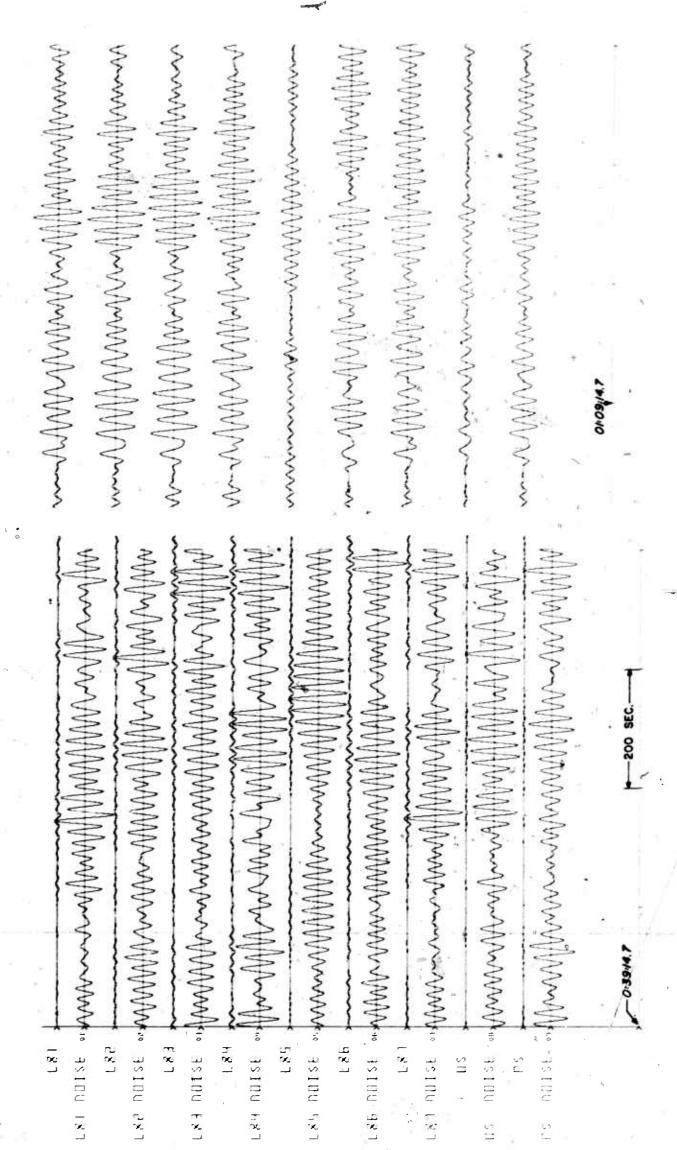
gure 43. Band pass filtered noise and signal traces with unphased and phased sums for an event in the North Atlantic Ridge recorded at TFO.

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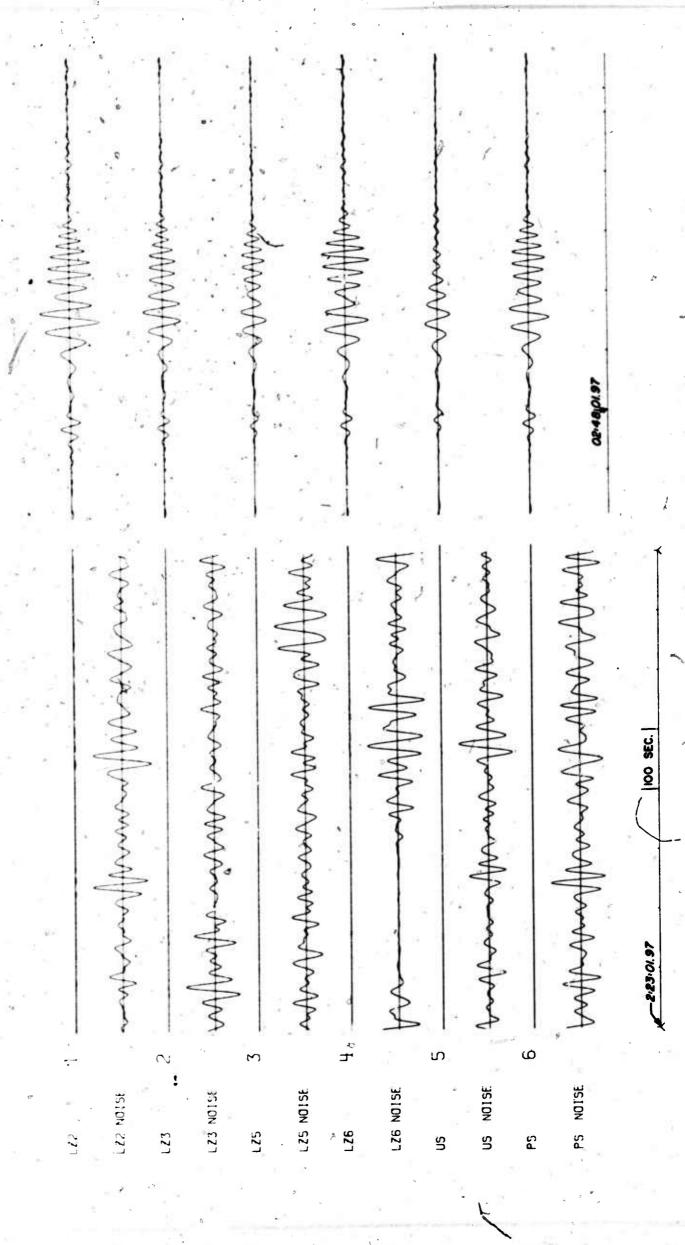
Figure 44. Band pass filtered noise and signal traces with unphased and phased sums for an event in El Salvador recorded at TFO.

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Band pass filtered noise and signal traces with unphased and phased sums for an event in Galapagos recorded at TFO. Figure 46.

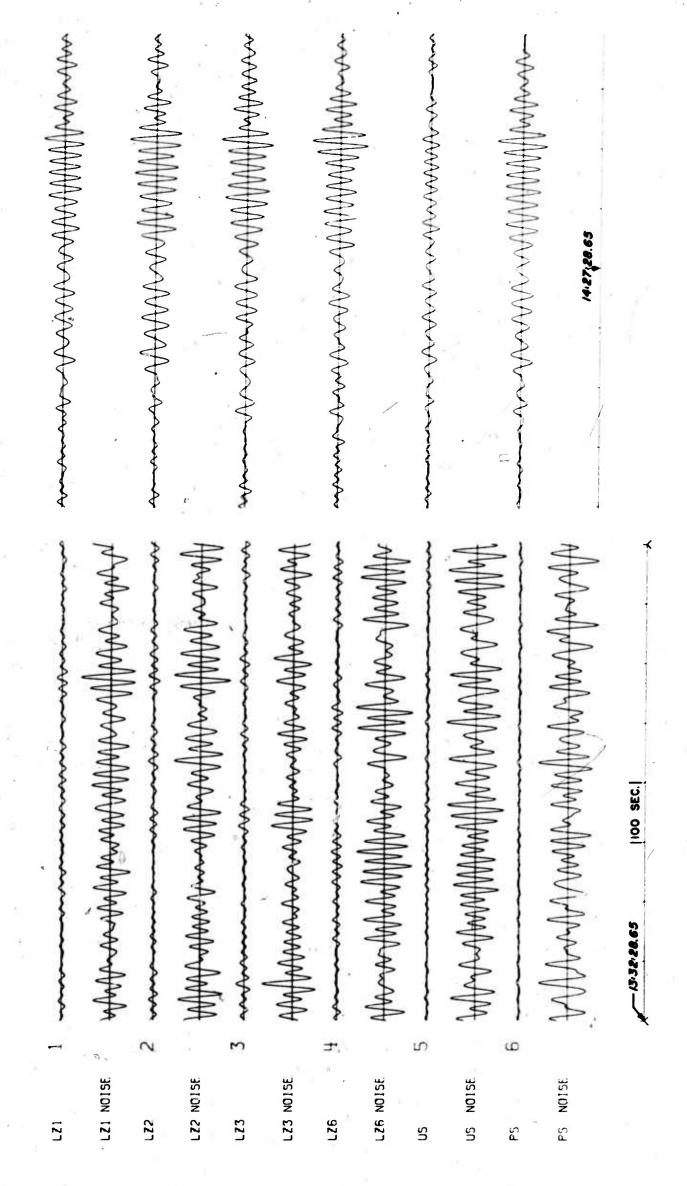


Figure 47. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Border Region of Greece - Albania recorded at TFO.

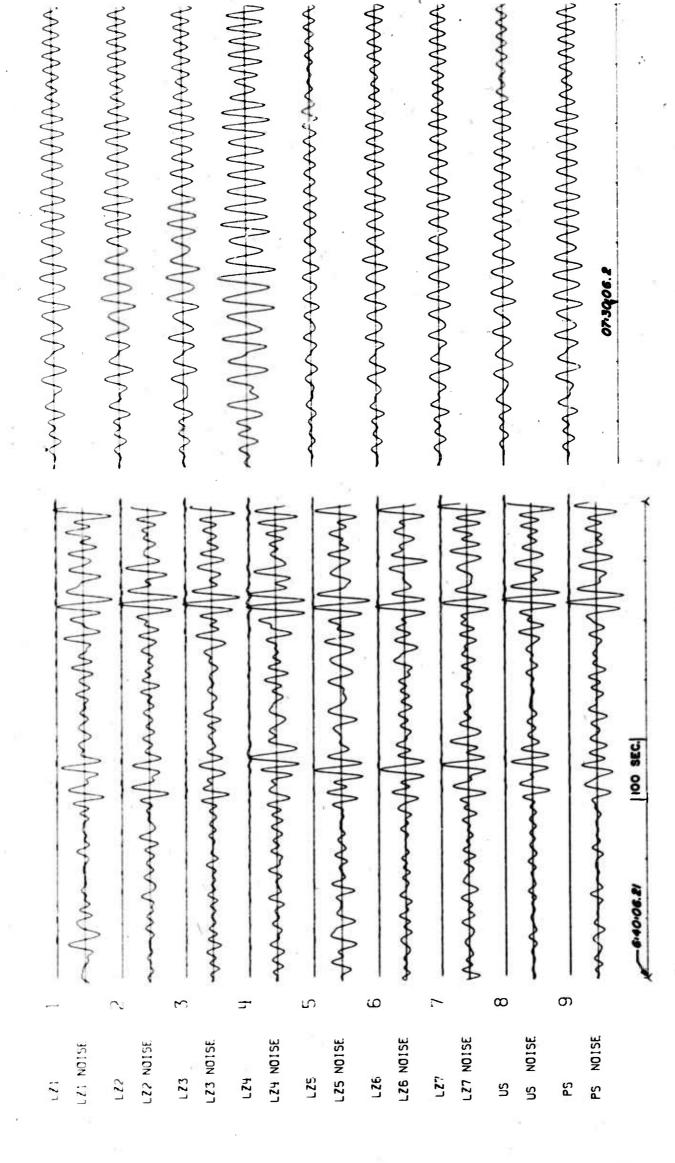
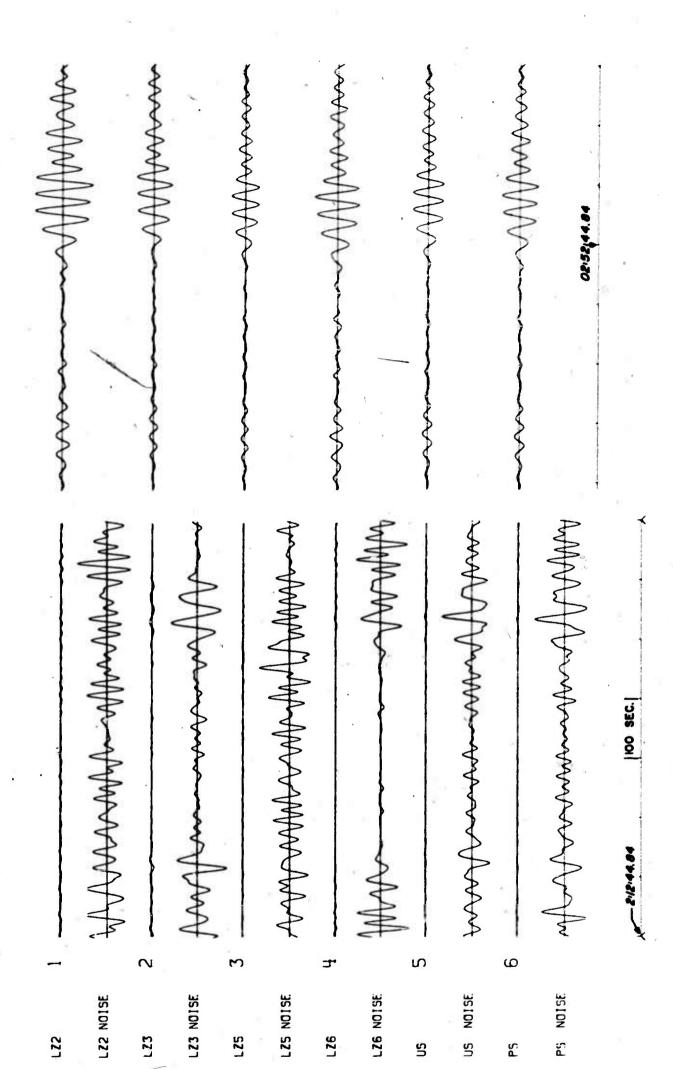


Figure 48. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Hindu Kush recorded at TFO.



and signal traces with for an event in Hokkaido Band pass filtered noise unphased and phased sums recorded at TFO. Figure 49.

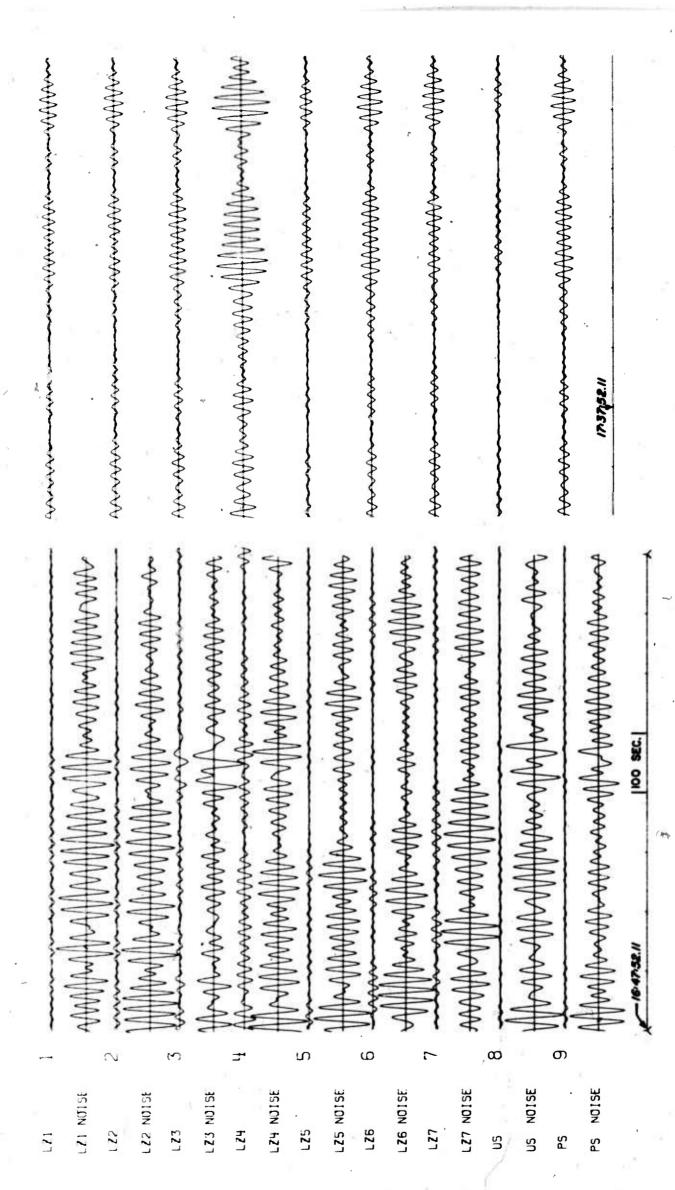


Figure 50. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kermadec Islands recorded at TFO.

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Figure 51. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kodiac Islands recorded at TFO.

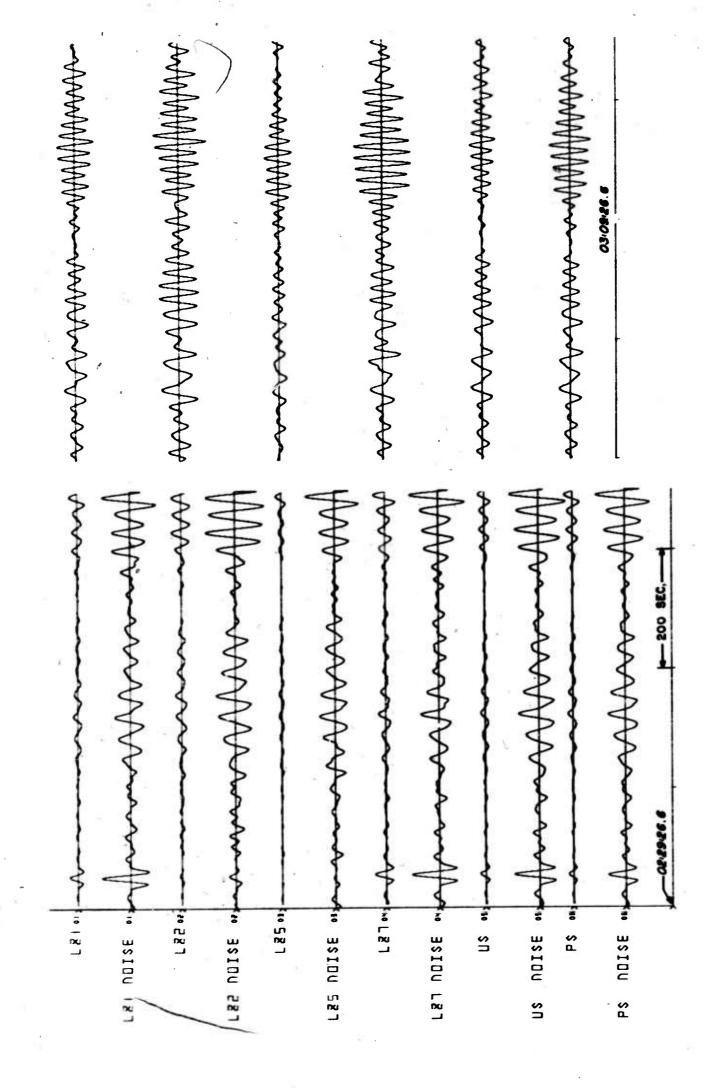
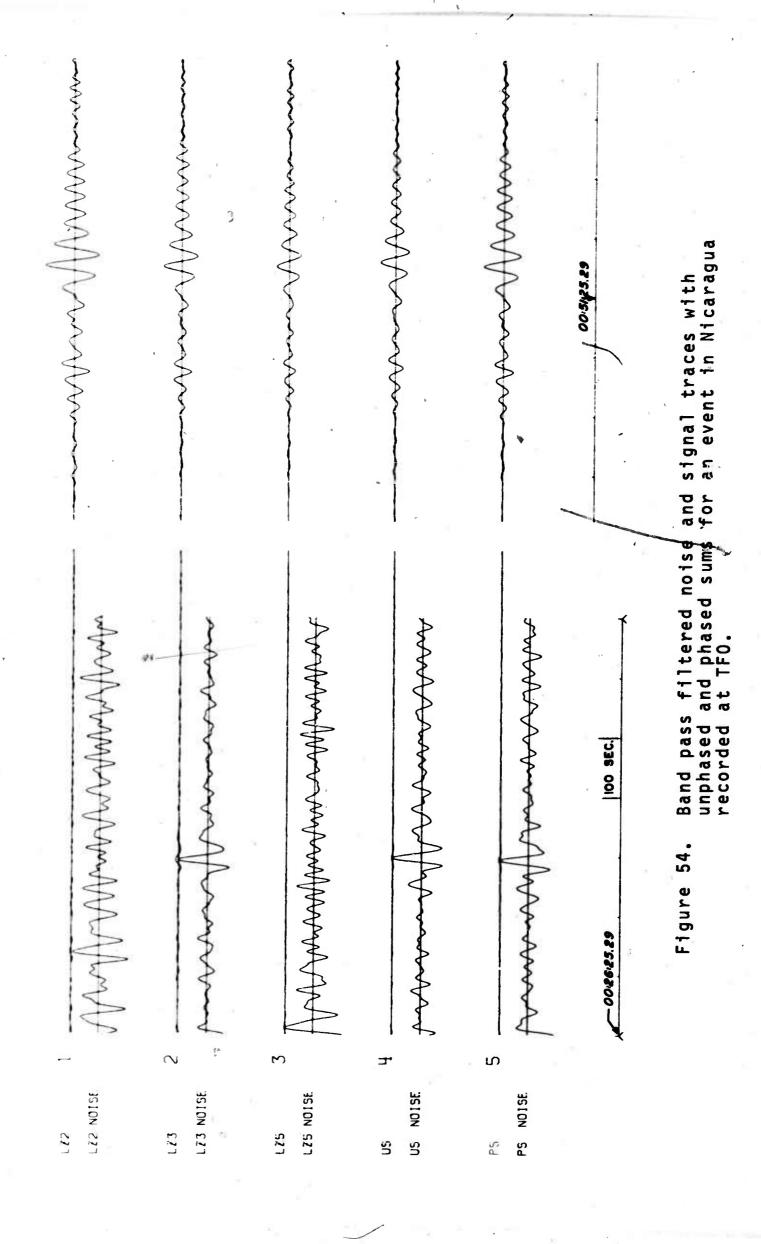
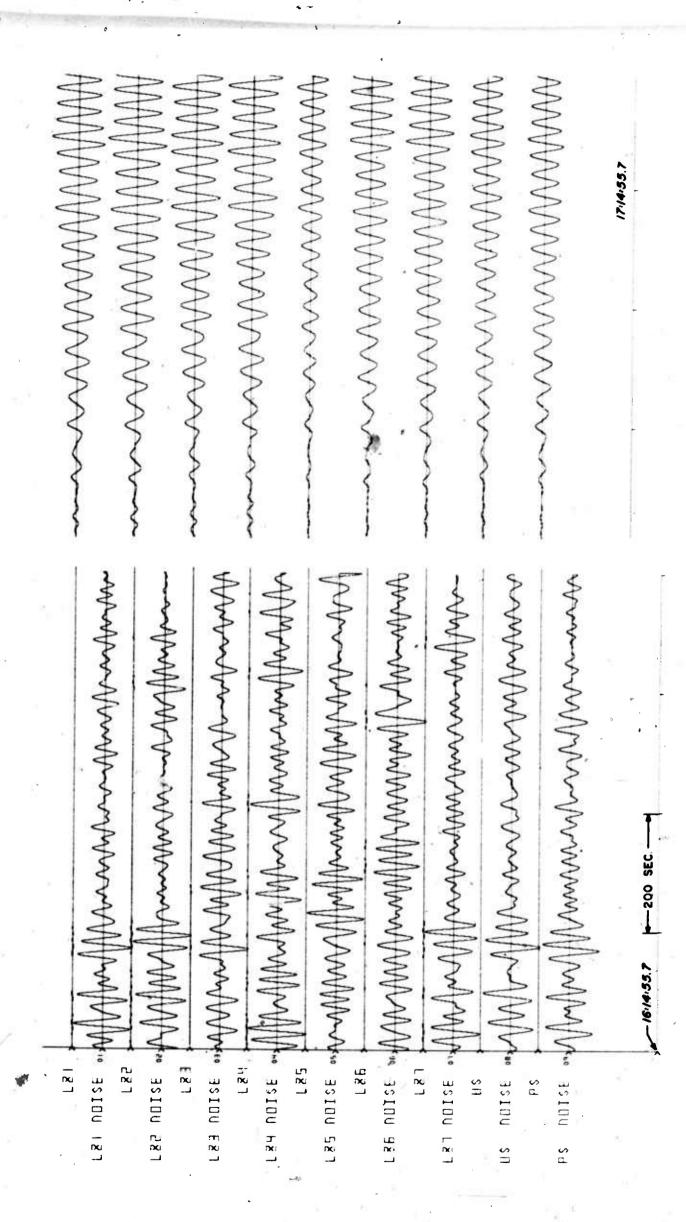


Figure 52. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kurile Islands recorded at TFO.

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Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinga recorded at TFO. Figure 53.



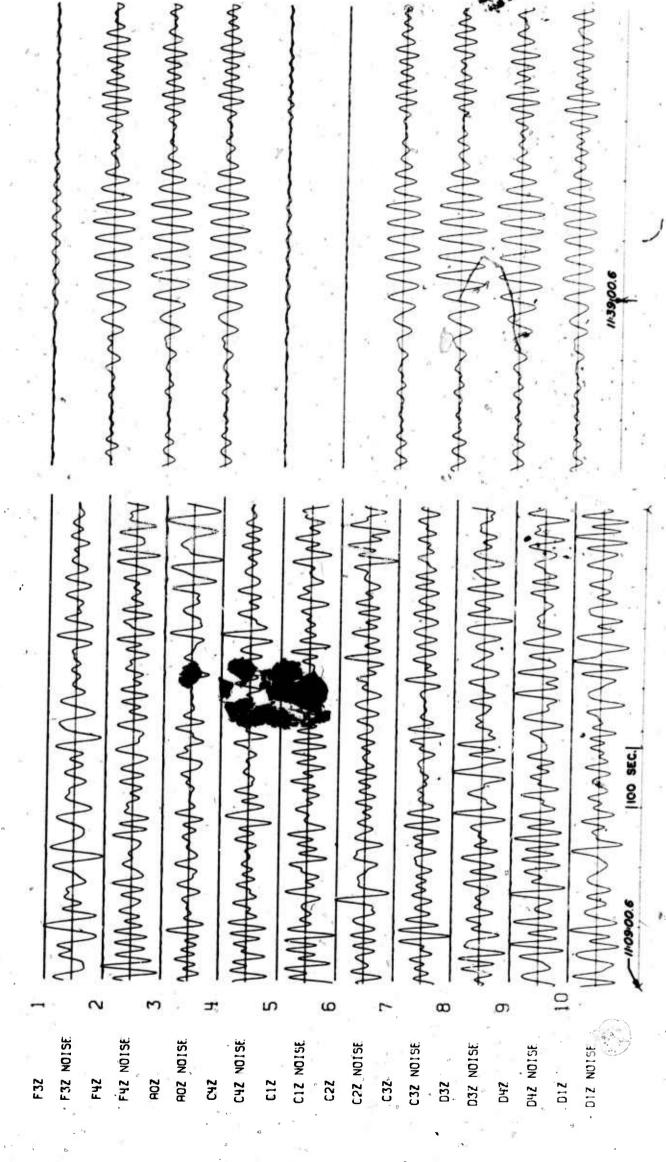


igure 55. Band pass filtered noise and signal traces with unphased and phased sums for an event in Sinkiang recorded at TFO.

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Figure 56. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Volcano Islands recorded at TFO.



igure 57a. Band pass filtered noise and signal traces with unphased and phased sums for an event in Costa Rica recorded at LASA.

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Figure 57b. Band pass filtered noise and signal traces with unphased and phased sums for an event in Costa Rica recorded at LASA.

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Figure 58a. Band pass filtered noise and signal traces with unphased and phased sums for an event in El Salvador recorded at LASA.

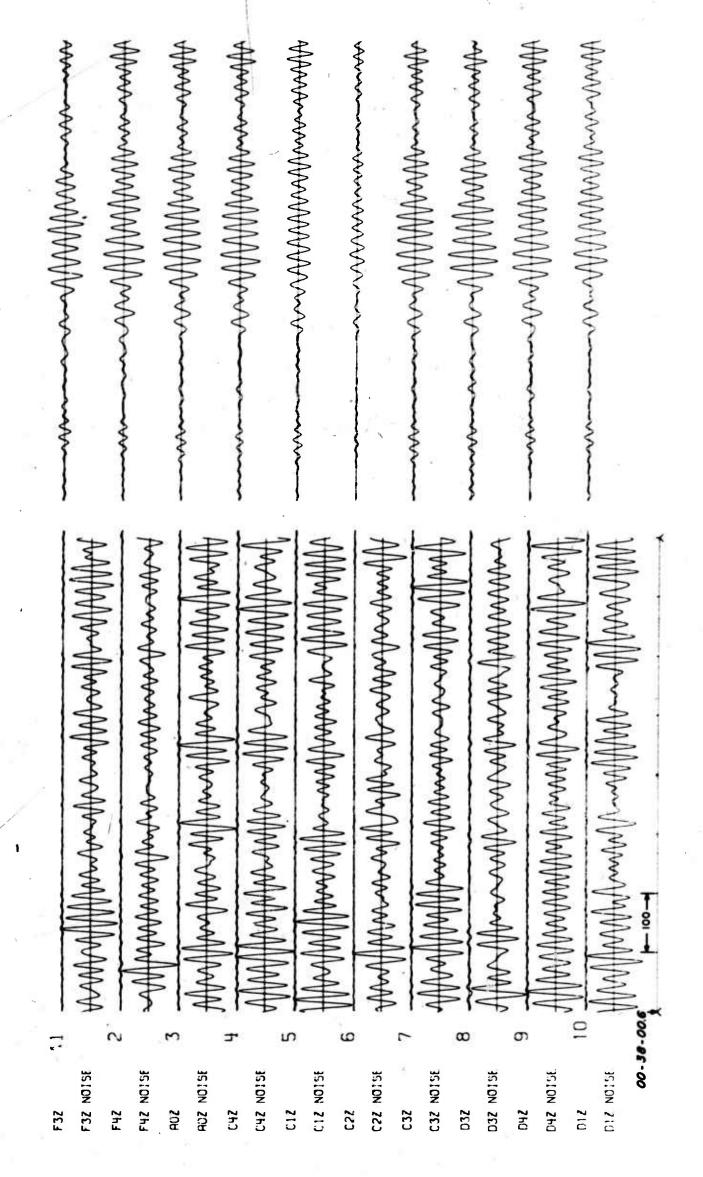
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Figure 58b. Band pass filtered noise and signal traces with unphased and phased sums for an event in El Salvador recorded at LASA.

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igure 59a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Fox Islands recorded at LASA.

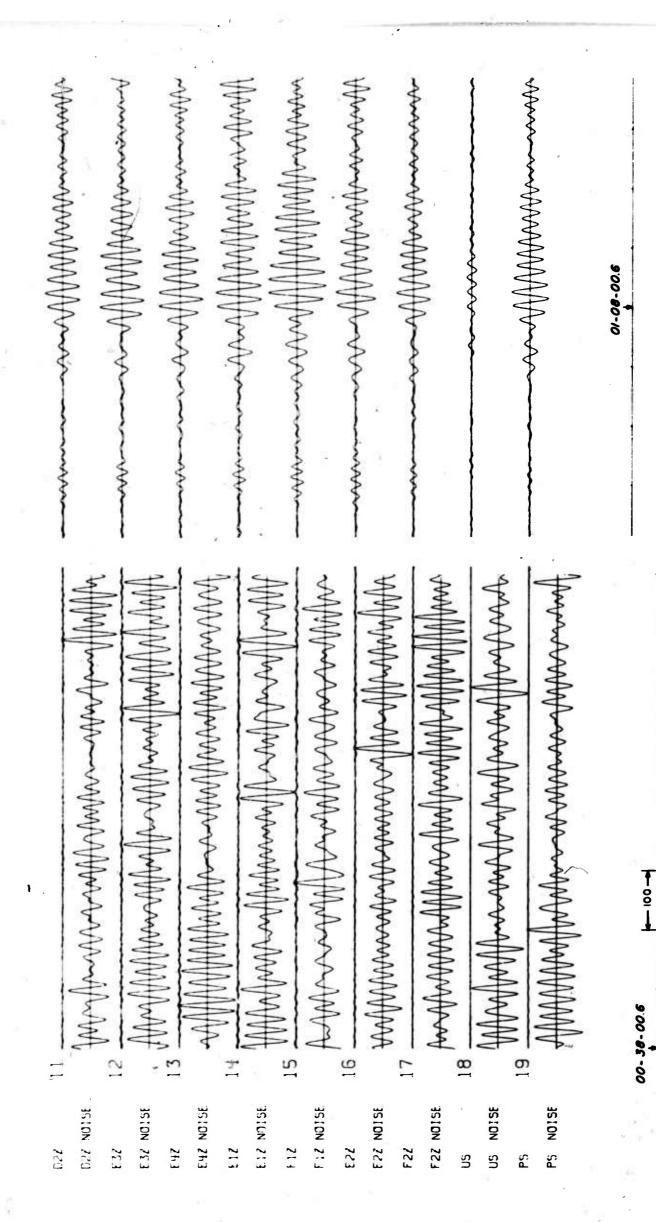


Figure 59b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Fox Islands recorded at LASA.

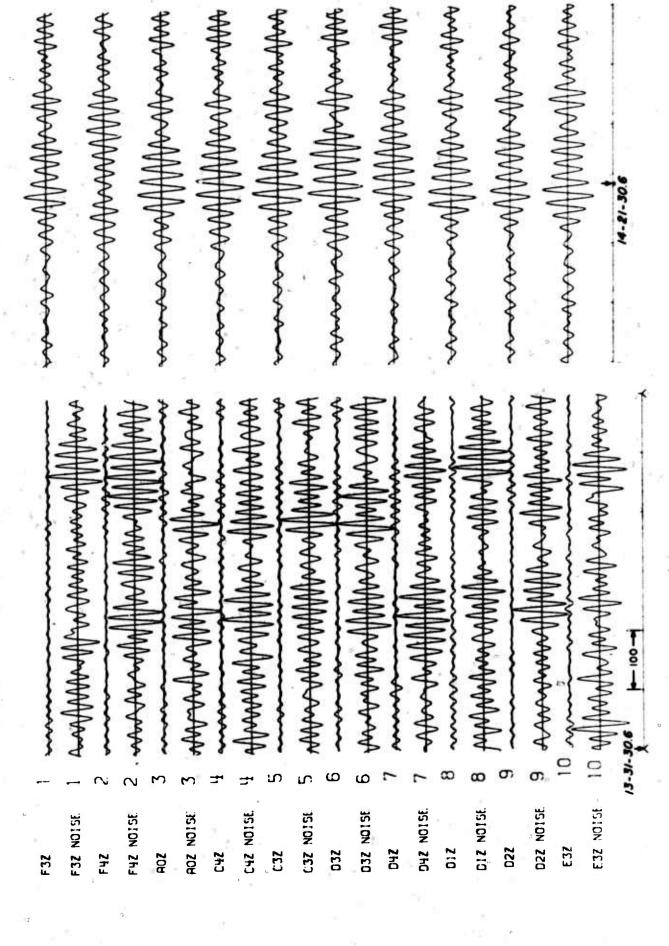
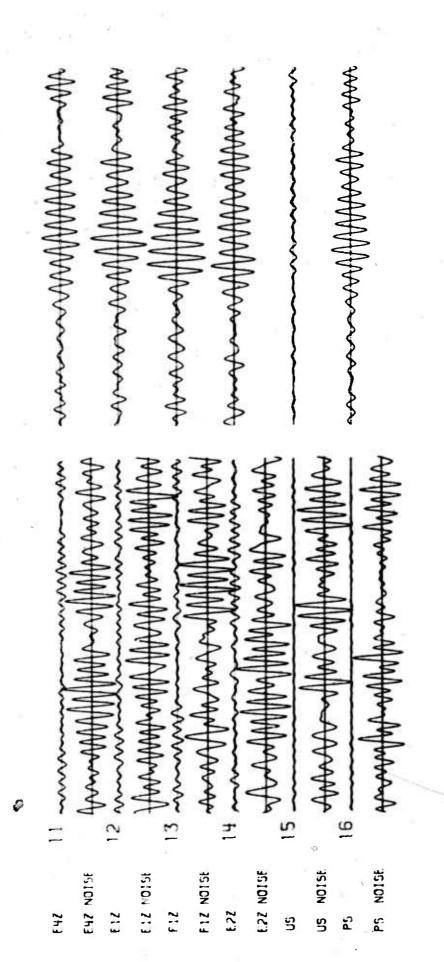


Figure 60a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Border Region of Greece - Albania recorded at



traces with Band pass filtered noise and signal traces wi unphased and phased sums for an event in the Border Region of Greece - Albania recorded at LASA. Figure 60b.

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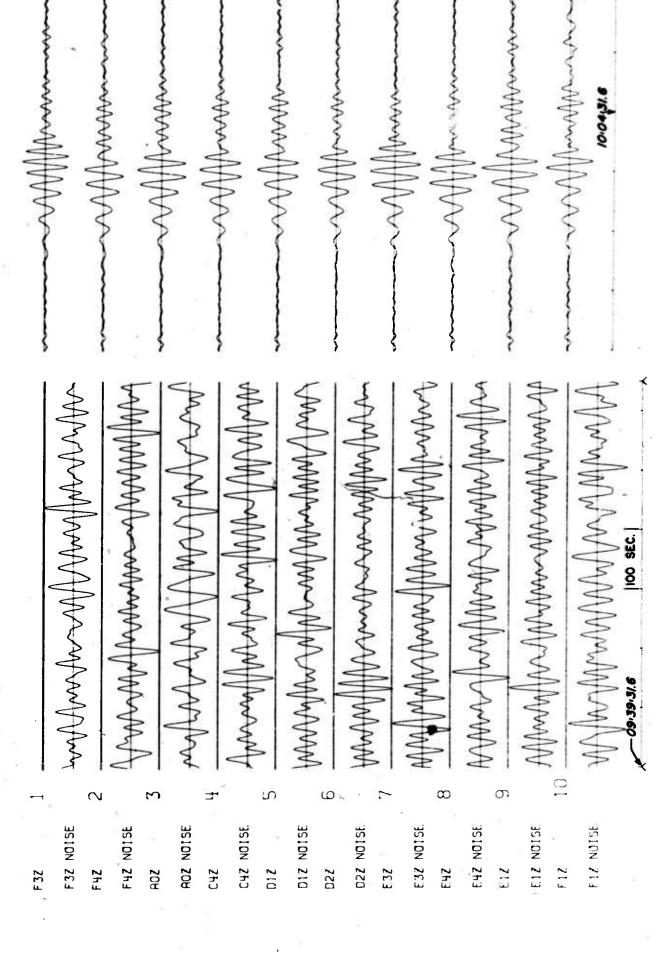


Figure 61a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Gulf of Alaska recorded at LASA.

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Figure 61b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Gulf of Alaska recorded at LASA.

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Figure 62a. Band pass filtered noise and signal traces with unphased and phased sums for an event in Hindu Kush recorded at LASA.

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Figure 62b. Band pass filtered noise and signal traces with unphased and phased sums for an event in dindu Kush recorded at LASA.

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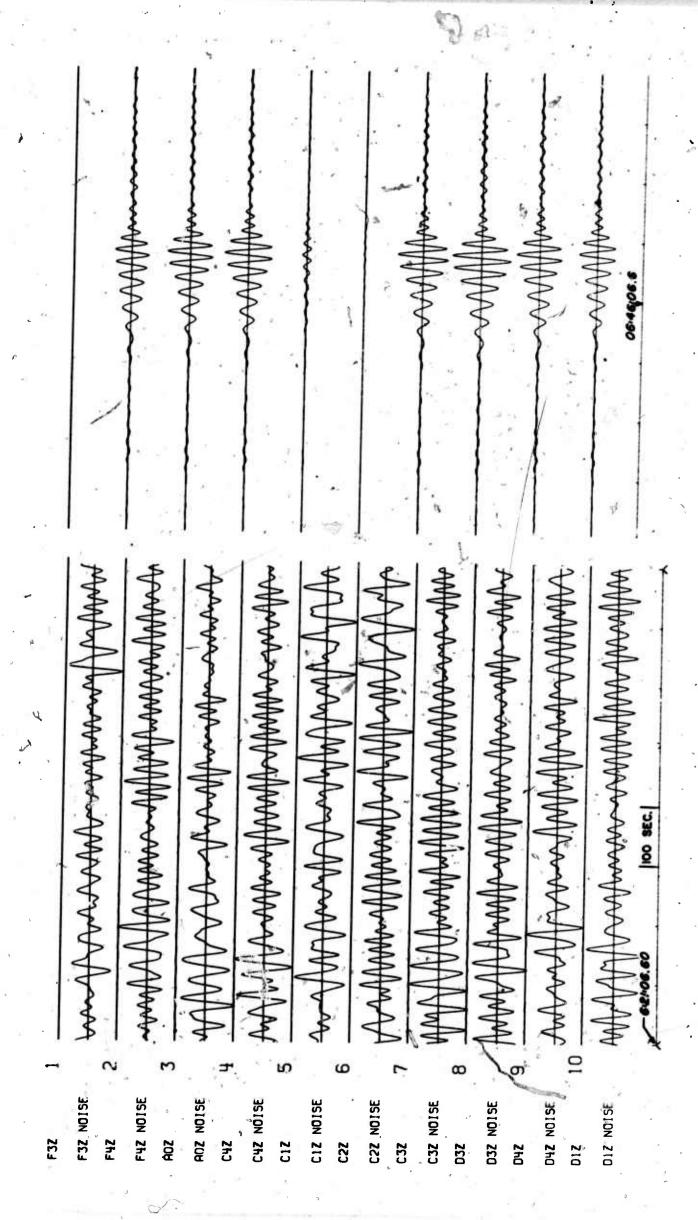
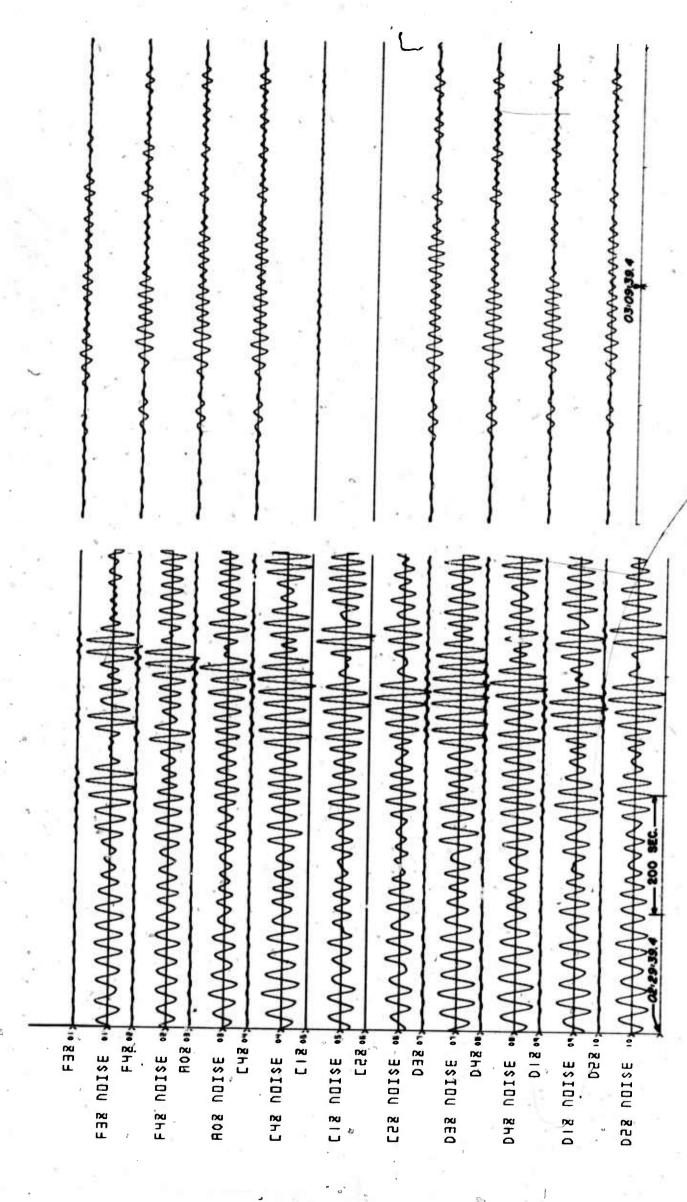


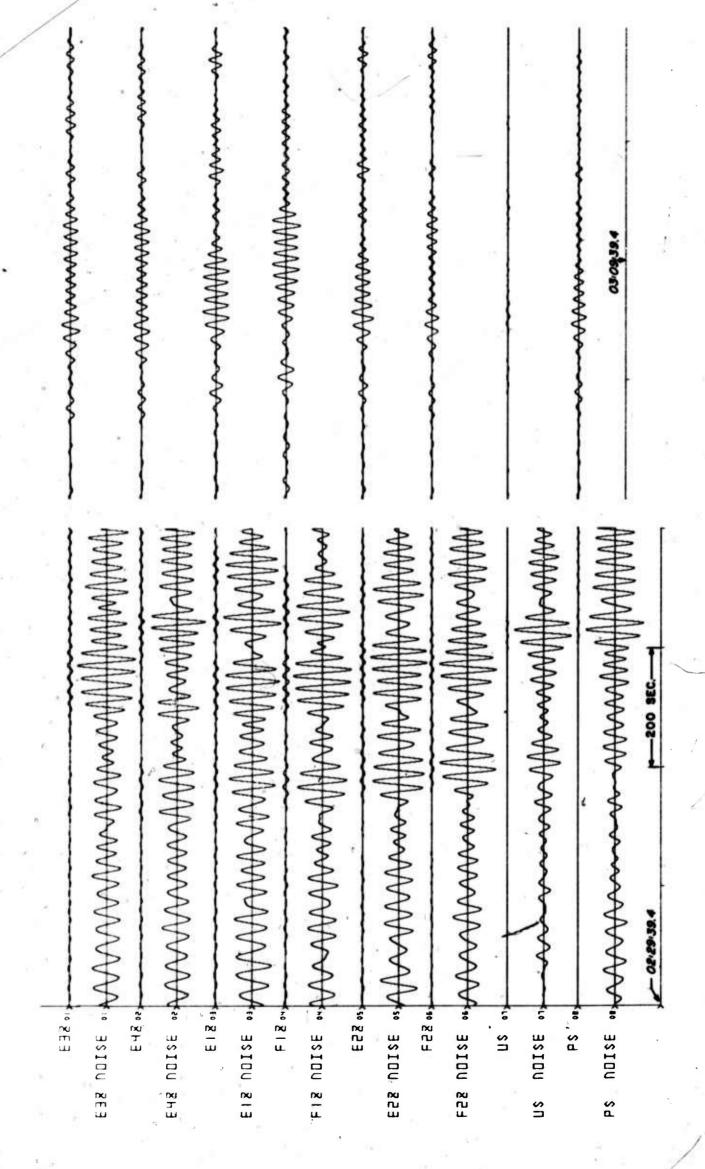
Figure 63a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kodiac Islands recorded at LASA.

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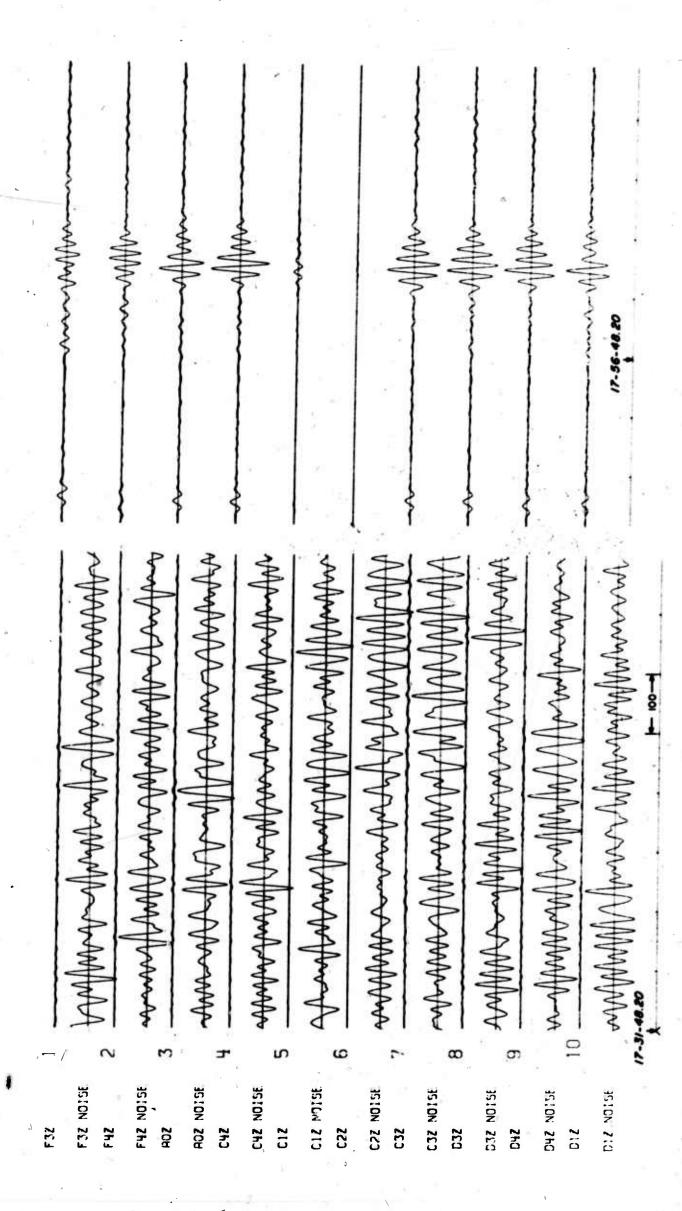
ure 63b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kodiac Islands recorded at LASA.



Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kurile Islands recorded at LASA. Figure 64a.



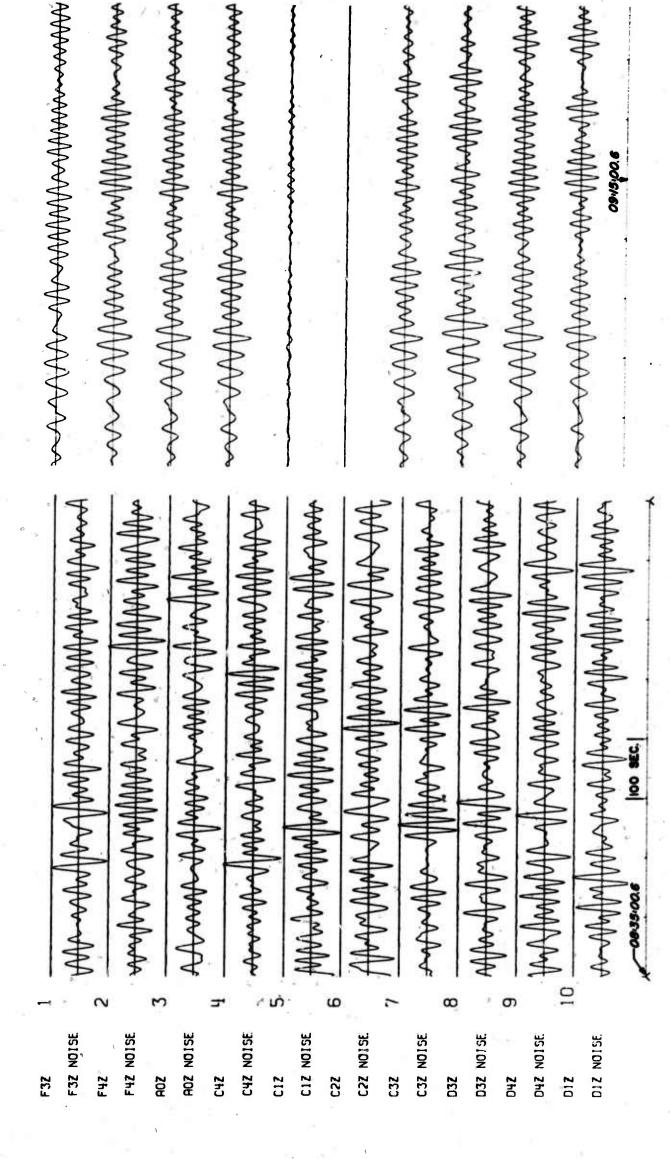
Band pass filtered noise and signal traces with unphased and phased sums for an event in the Kurile Islands recorded at LASA. Figure 64b.



Band pass filtered noise and signal traces with unphased and phased sums for an event in Mexico recorded at LASA. Figure 65a.

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Band pass filtered moise and signal traces with an event in Mexico for unphased and phased sums recorded at LASA. Figure 65b.



Band pass filtered noise and signal traces with for an event in the unphased and phased sums Near Islands recorded at Figure 66a.

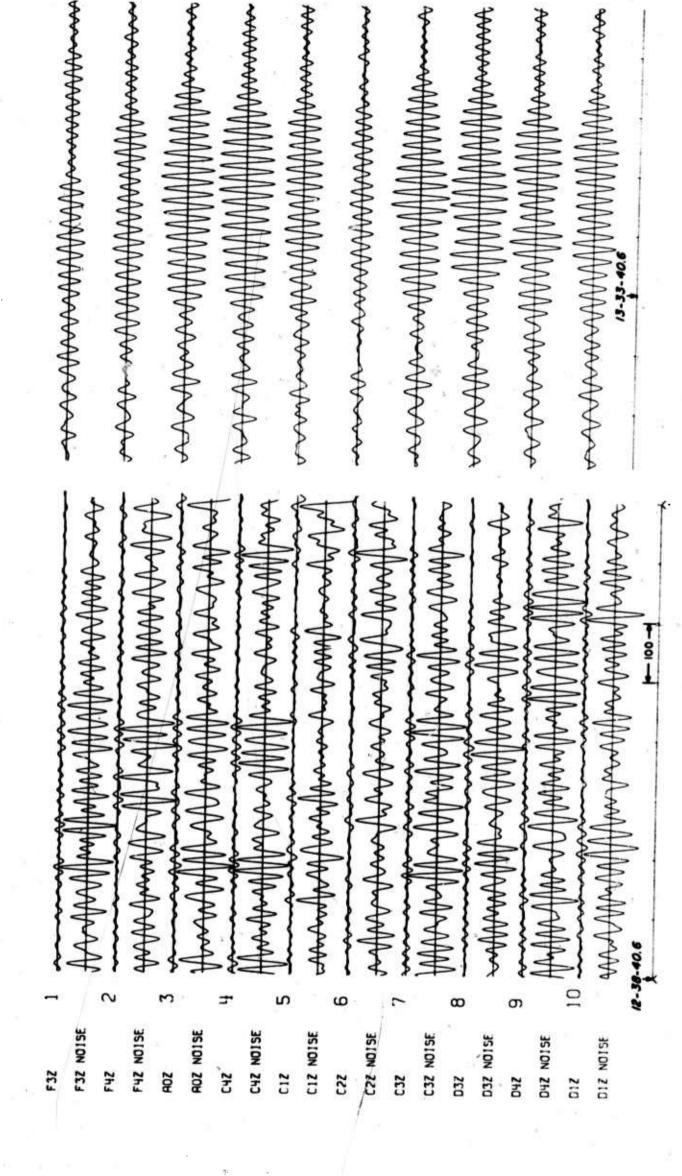
00012100.6

SCOUNT SOUTH bor-Malara College Malle as a sale of Aganga Malle as a sale of the control of th sall har from Manhahar Manhall Mallerall har 13 15 16 17 138 7 NOISE NO 1 SE NO 1 SE NOISE NO1SE NO 1 SE. NOISE

Band pass filtered noise and signal traces with unphased and phased sums for an event in the Near Islands recorded at LASA. Figure 66b.

00 SEC.

00.3500.6



Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinea recorded at LASA. Figure 67a.

13-33-40.6

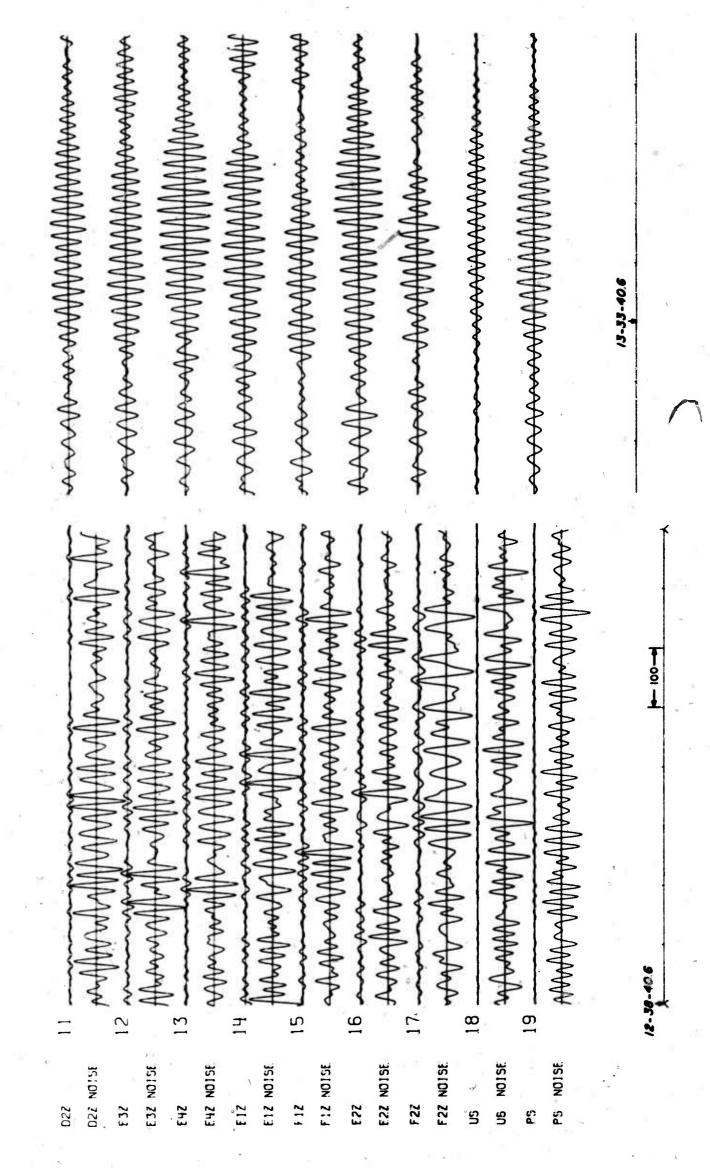


Figure 67b. Band pass filtered noise and signal traces with unphased and phased sums for an event in East New Guinea recorded at LASA.

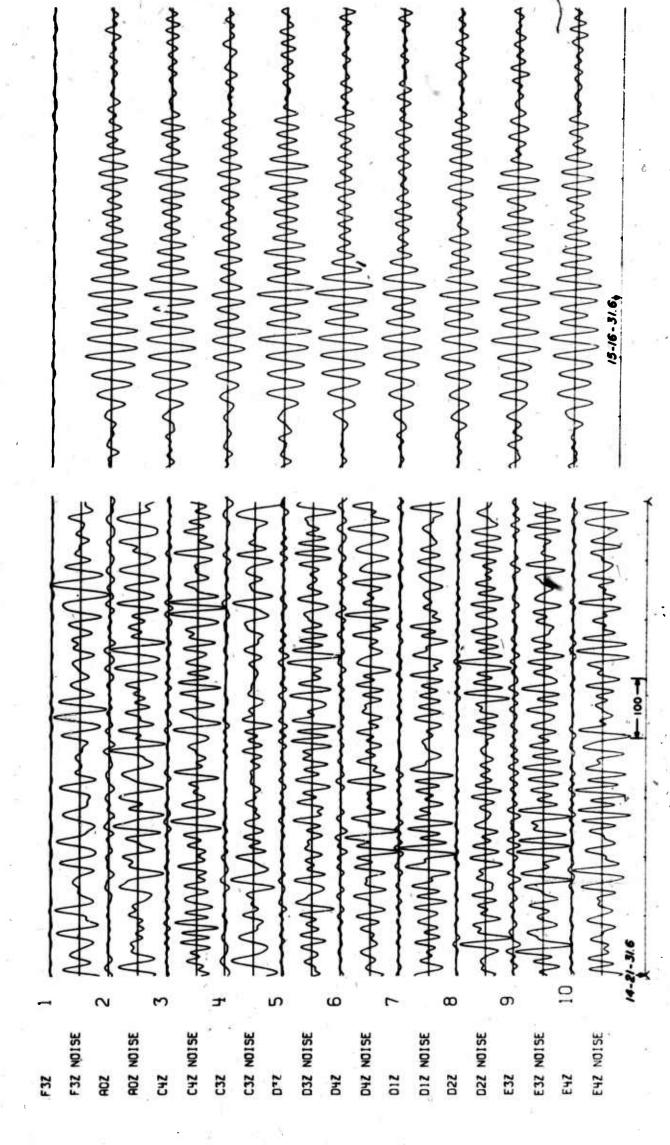


Figure 68a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Philippine Islands recorded at LASA.

FIZ NOISE 12 JUMPHY OF THE CONTRACT OF THE CON

15-16-31.6

Figure 68b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Philippine Islands recorded at LASA.

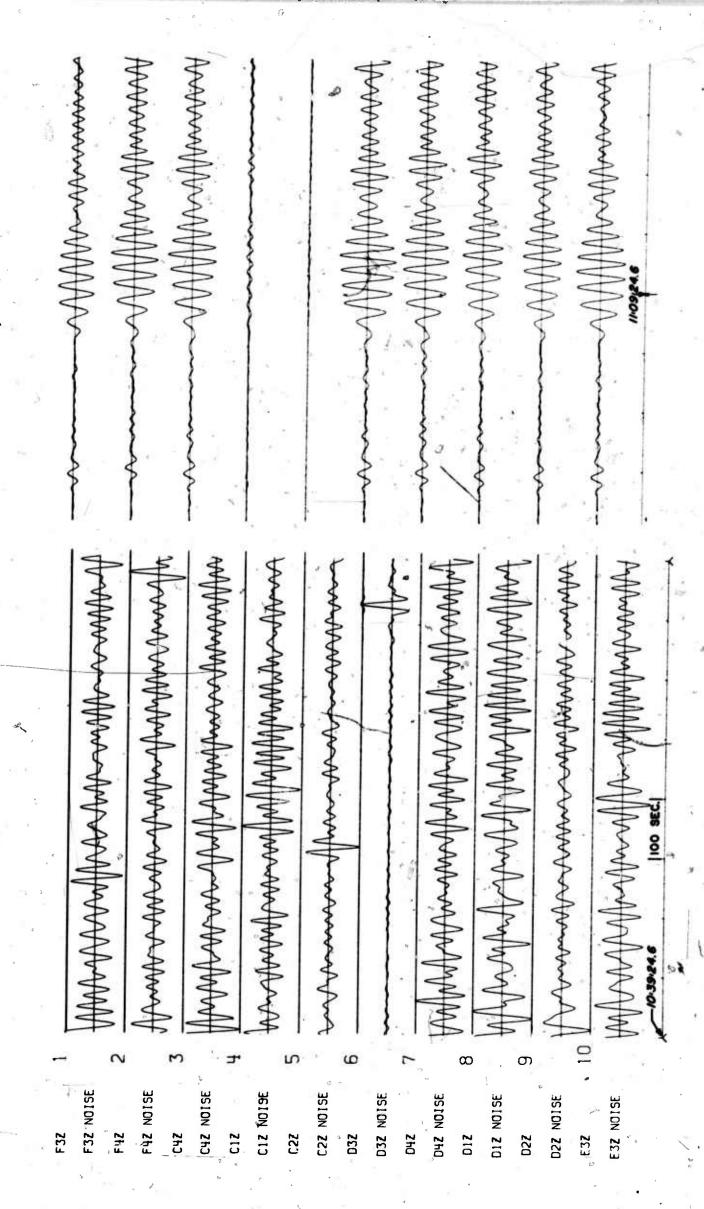


Figure 69a. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Rat Islands recorded at LASA.

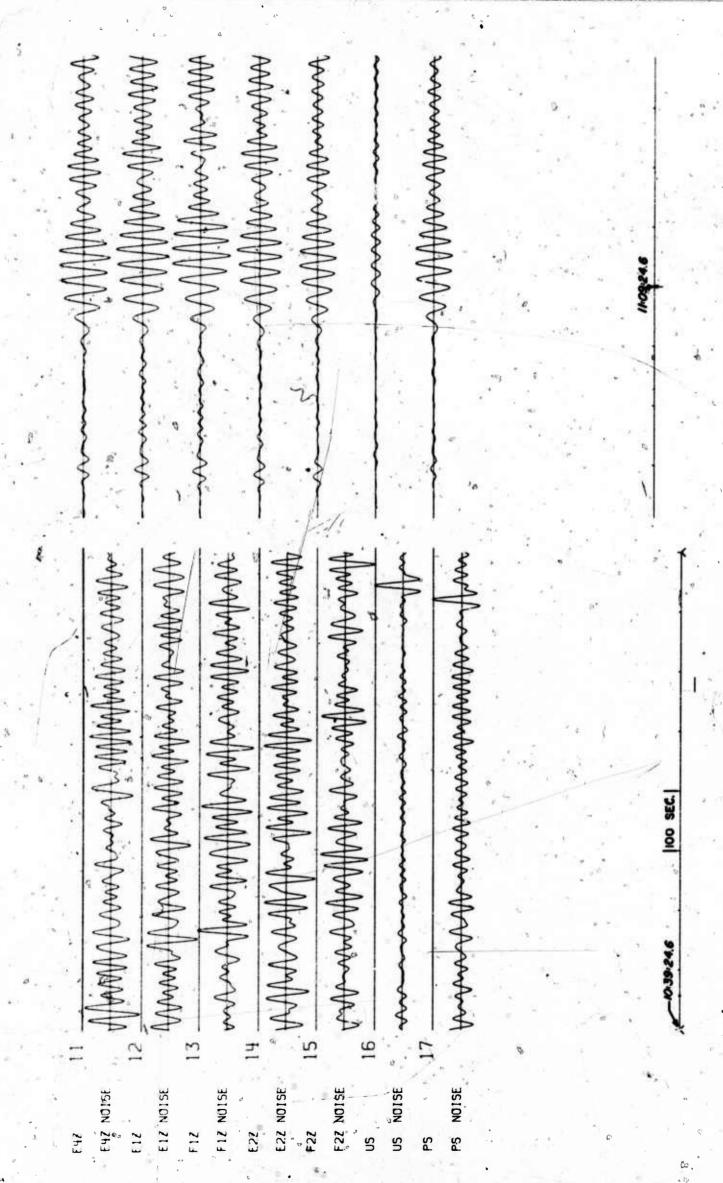
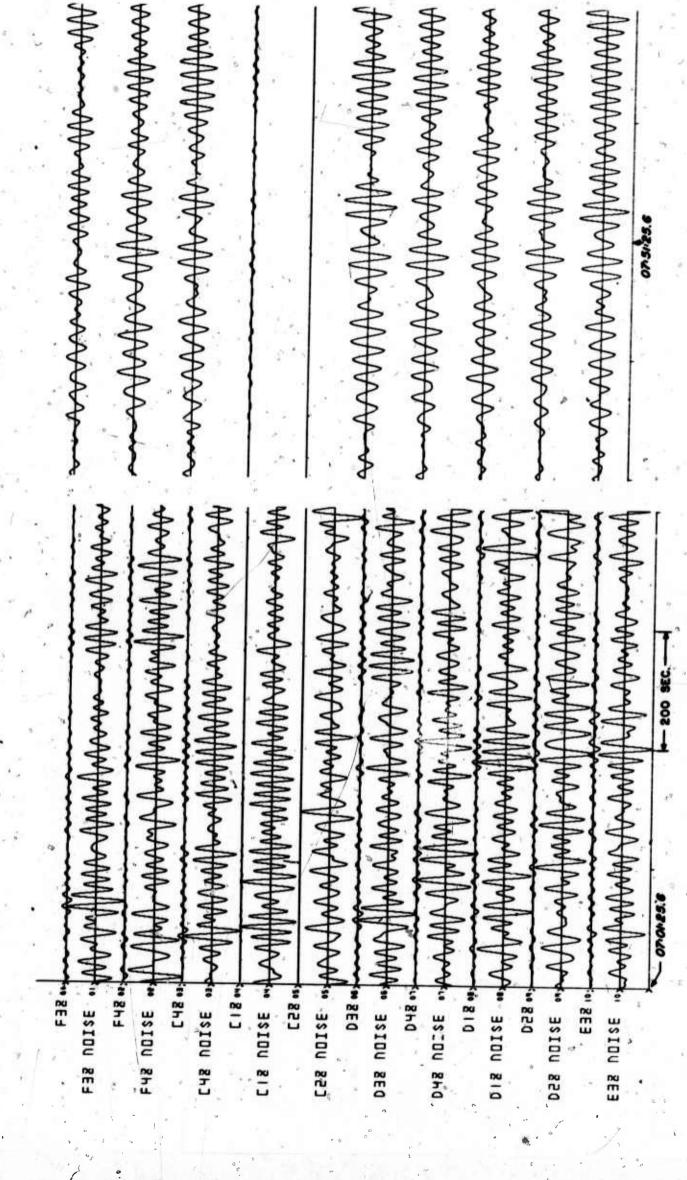


Figure 69b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Rat Islands recorded at LASA.



Band pass filtered noise and signal traces with an event in the Ryukyu Islands recorded at LASA. unphased and phased sums for Figure 70a.

3.

075125.6

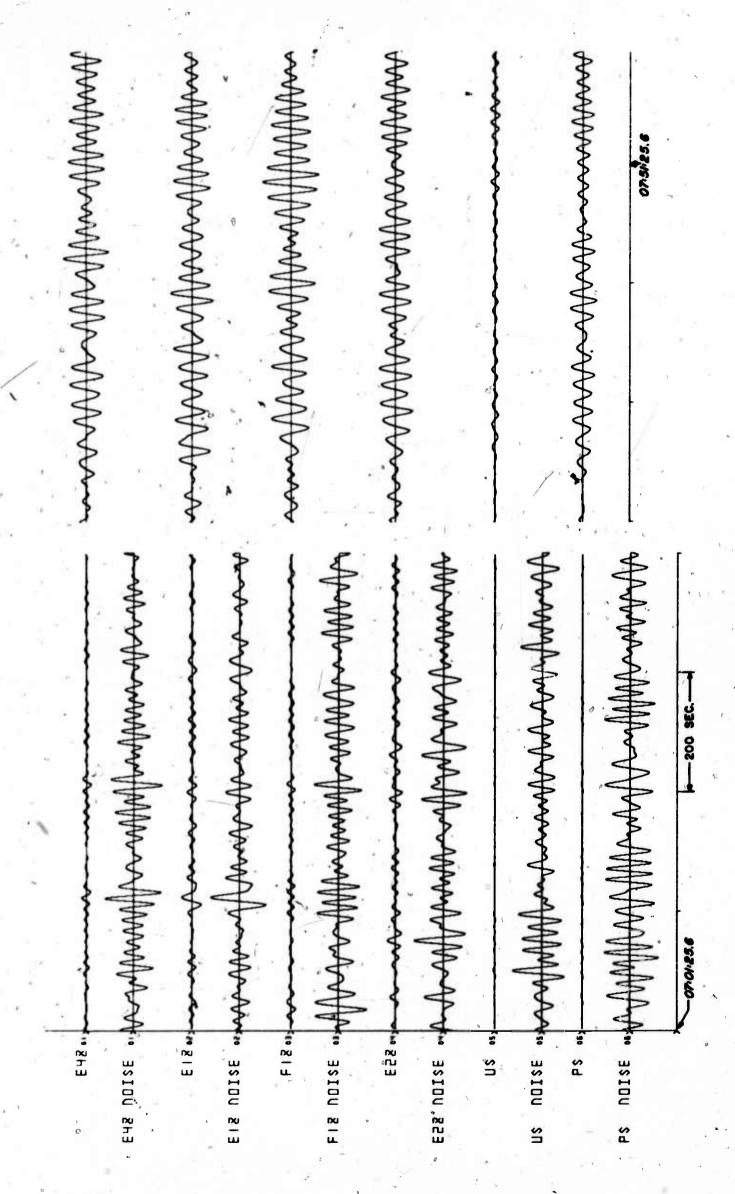
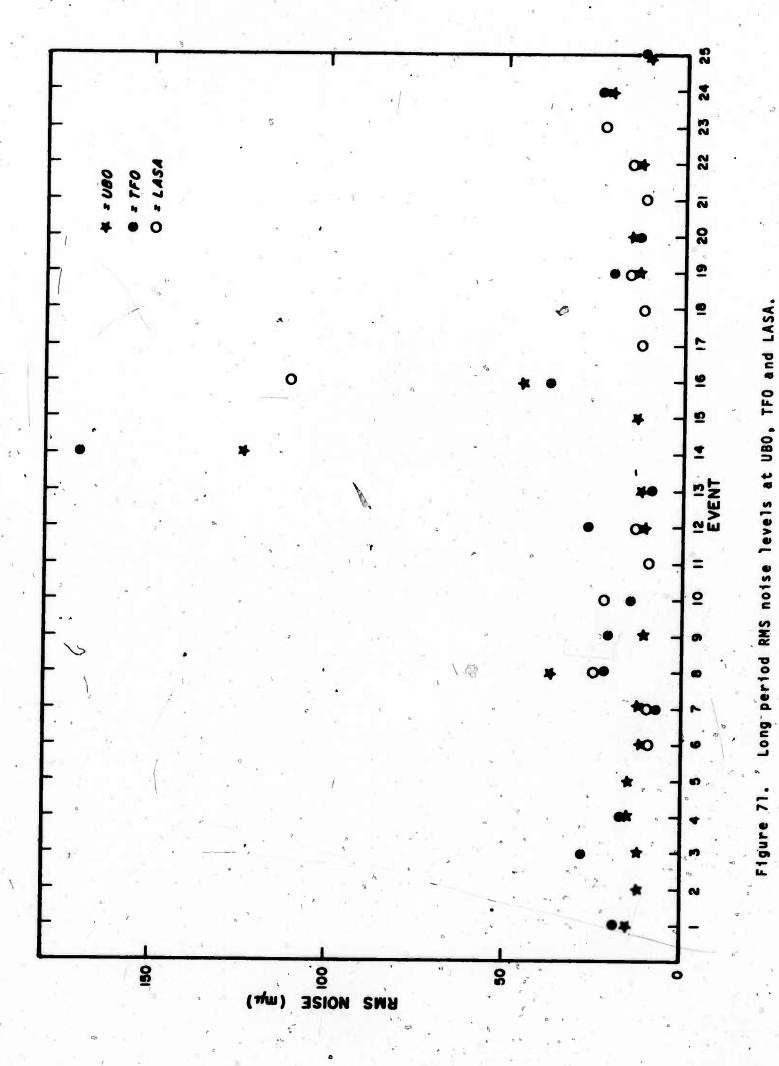


Figure 70b. Band pass filtered noise and signal traces with unphased and phased sums for an event in the Ryukyu Islands recorded at LASA.



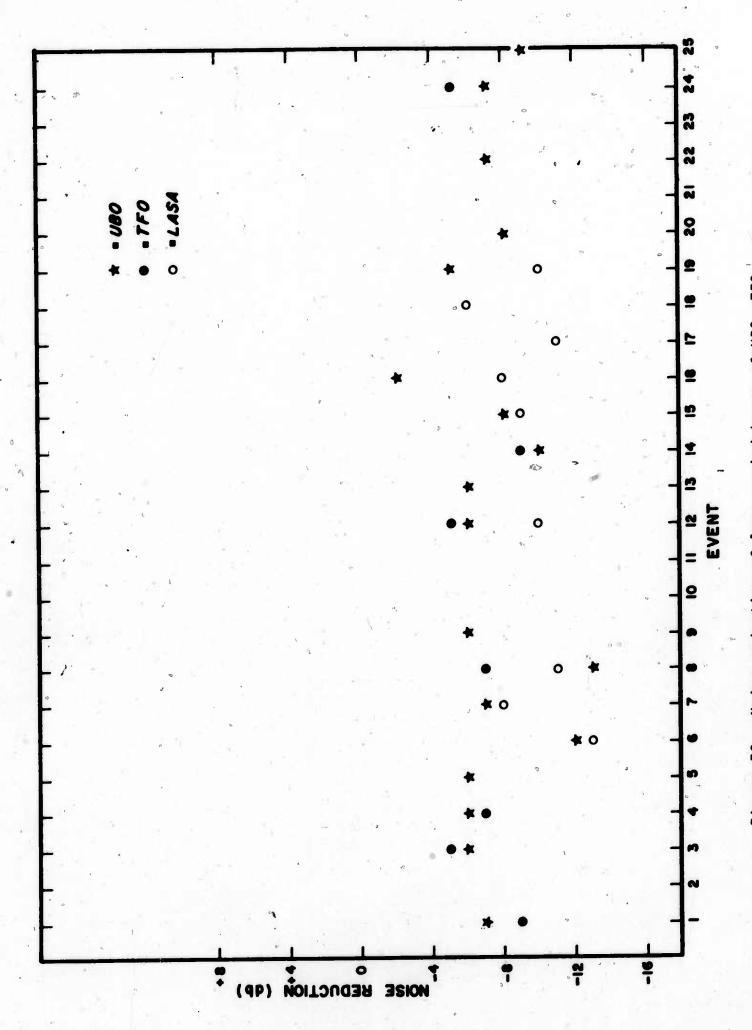
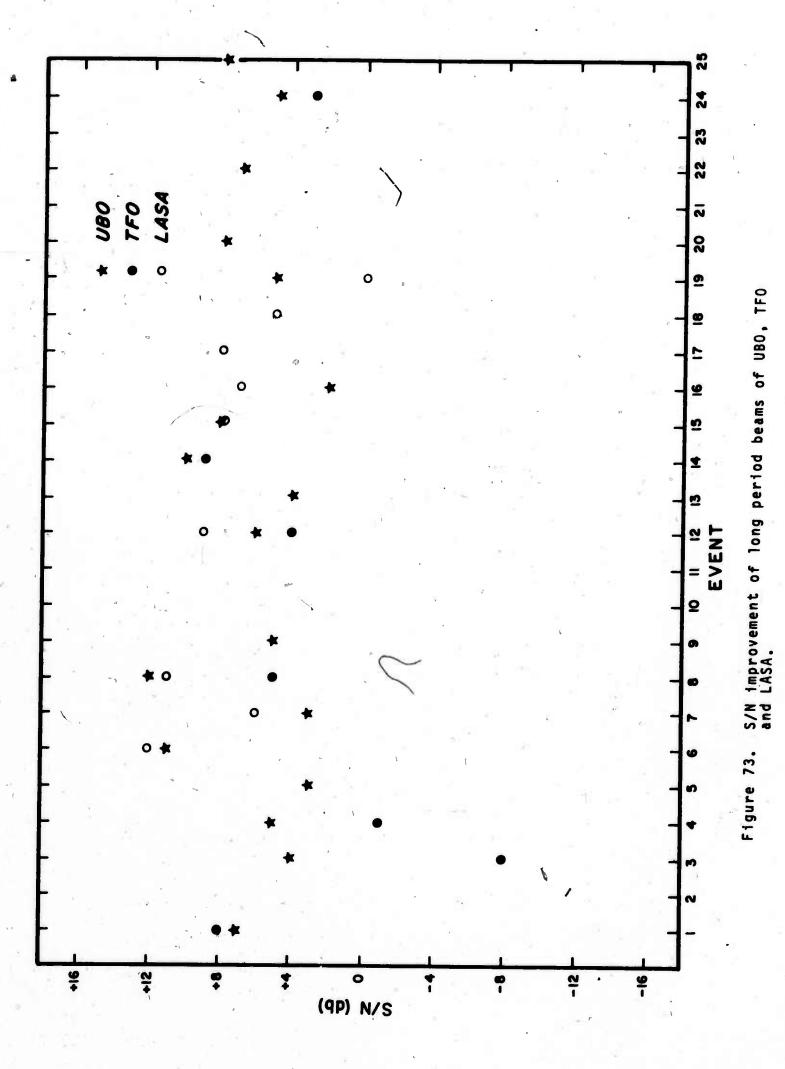


Figure 72. Noise reduction of long period beams of UBO, TFO and LASA.



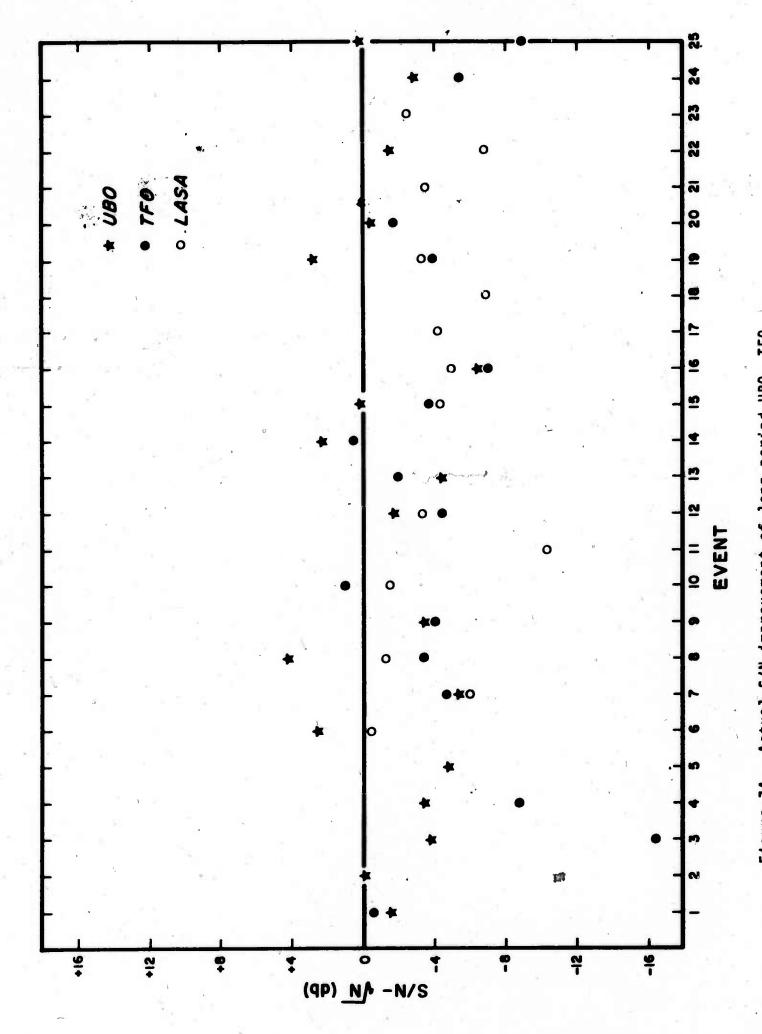


Figure 74. Actual S/N improvement of long period UBO, TFO and LASA beams minus Ni.

TABLE I

Source Parameters of Events and the Specific Recording Instruments of the Arrays used in Computation of Group Velocity Dispersion

•		n			080	0	TFO	0	LASA	A
EVENT	DATE	ORIGIN	LOCATION Lat. Long.	N.	DISTANCE	INSTRUMENT	DISTANCE	INSTRUMENT	DISTANCE	INSTRUMENT
Albanta	26 Aug 69	02 15 38.8	41.8N	20.15	9583	LPZ1	10220	LPZ1	8853	D3.7
N. Atlantic	06 Sep 69	14 30 39.5	36.9N	11.9W	1,	•	8535	LPZ1		
N. Atlantic Ridge	30 Oct 69	08 37 38.4	45.5N	27.5W	6370	LPZ2			6751	F 3.7
Balleny Islands	29 Jun 69	17 09	62.85	166.3E	. 1		•		16326	26.
Costa Rica	04 Jul 69	11 16 01.0	7.4N	82.7W	4538	LPZ1	4186	1 971	4925	242
El Salvador	28 Jun 69	04 34 42.6	12.8N	89.2W	3632	LPZ1	3256	LPZ2	4067	F47
Galapagos	26 Jun 69	02 30 58.4	2.0N	90.5W	4636	LPZ1	4145	LPZI		•
Hindu Kush	08 Aug 69	06 30 57.1	36.4N	70.9E	b •	•	12236	LPZI	10859	F 3.7
Hokkaldo	27 Jun 69	02 15 46.3	42.4N 1	142.9E	8339	LPZ1	8683	LPZ?		
Kermadec Islands	28 Aug 69	16 49 56.8	31.85	177.8W	10653	LPZ1	10121	LPZ1	33	
Kodfac Islands	28 Jul 69	06 29 53.9	57.5N	153.9W	3675	LPZ1	4077	LPZ1		1
Kurile Islands	22 Jun 69	02 33 52.8	49.2N 1	158.5E	6936	LPZI			6671	F37
Kurile Islands	14 Aug 69	14 19 01.6		147.5E	7951	LPZ1				
W. New Guinea	05 Jul 69	01 44 01.1	3.85	31.5E			12702	LPZ2		\
Nicaragua	24 Jun 69	00 35 05.5	11.7N	85.7W	3989	LPZ1	3636	LP22		
Rat Islands	22 Jun 69	10 45 24.5		79.9W	5404	LPZI	1112	LPZ1	5212	F3Z
Sinklang	14 Sep 69	16 15 24.8	39.5N	74.9E	11113	LPZI	11760	1267		•
Soloman Islands	14 Jun 69	03	07.95	159.0E	10697	LPZI	10478	LPZ2	11012	F32
Unimak Islands	20 Jun 69	02 37 51.5	53.2N 1	162.4W	•	•	4488	LPZ2	3949	F3Z
Yugoslavia	26 Oct 69	15 36 51.8	44.9N	17.3E	9260	LPZI	-		8	

TABLE II

Source Parameters of Events Analyzed by Beam Formatign

EVENT DATE ORIGIN TIME LAT. LONG. Albania 26 Aug 69 02 15 38.8 41.8N 20.1E Argentina 25 Jul 69 06 06 42.4 25.6S 63.3N N. Atlantic 29 Jul 69 06 06 42.4 25.6S 63.3N N. Atlantic 29 Jul 69 06 04 25.5 19.9N 64.1H N. Atlantic 22 Jul 69 08 37 38.4 45.5N 27.5N Cost a Rice 22 Jun 69 08 34 42.6 12.8N 82.7N El Salvador 24 Oct 69 10 43 42.6 12.8N 82.7N Glabagos 12 Oct 69 10 43 42.6 12.8N 82.7N Glabagos 26 Jun 69 04 614.6 52.5N 16.6M Glabagos 12 Oct 69 10 45.6 52.5N 16.6M Glabagos 12 Oct 69 10 45.6 52.5N 14.7N Hakkaido 27 Jun 69 06 30 57.1 42.4N 142.9E Kurita Is. 28 Jun 69 07 30 55.9 57.5N 17.8N <th></th> <th>10 10</th> <th>LOCATION</th> <th></th>											10 10	LOCATION	
26 Aug 69 02 15 38.8 41.8N 20.0. 25 Jul 69 06 06 42.4 25.6S 63. 29 Jul 69 06 06 42.5 19.9N 64. 22 Oct 69 08 37 38.4 45.5N 27. 22 Jun 69 07 02 15 2.1 18.1S 71. 24 Oct 69 04 4 42.6 12.8N 89. 24 Oct 69 04 4 42.6 12.8N 89. 25 Jun 69 06 46 14.6 52.5N 168. 26 Jun 69 07 23 0 58.4 2.0N 90. 27 Jun 69 07 03 05.1 33.4N 70. 28 Jun 69 06 47 59.4 59.5N 142. 28 Jun 69 06 29 53.9 57.8 153. 28 Jun 69 06 29 53.9 57.8N 158. 28 Jun 69 07 03 04.9 5.5 11.7N 85. 29 Jun 69 07 03 04.9 5.5 11.7N 85. 20 Jun 69 07 03 04.9 5.5 11.7N 126. 20 Jun 69 07 03 04.9 5.5 11.7N 126. 20 Jun 69 07 03 04.9 5.7N 74. 20 Jun 69 07 03 04.9 28.1N 179. 20 Jun 69 07 03 04.9 28.1N 179. 20 Jun 69 07 03 04.9 28.1N 142.		1	۵۱	ATE	•		ol	RIGI	N TIME		LAT.	LONG.	
25 Jul 69 06 42.4 25.65 63.82 29 Jul 69 00 40 42.5 19.9N 64. 84. 82.0ct 69 08 37 38.4 45.5N 27.1 18.15 71.1 6 Jul 69 10 21 52.1 18.15 71.1 6 Jul 69 11 16 O1.0 7.4N 82. 24 Oct 69 04 34 42.6 52.5N 168.0		t _a	9	67			0	_	38.		3.8	•	
Ridge 30 Oct 69 08 37 38.4 45.5N 27.1 18.15	Argentina	4	2	3			ō		4		5.6	•	
1	N. Atlantic .		6				0	_	4		•	64.1W	
Chile 22 Oct 69 10 21 52.1 18.15 71.6 old Jul 69 11 16 01.0 7.4N 82.0 old Jul 69 04 34 42.6 12.8N 89.0 old Jul 69 00 46 14.6 52.5N 168.0 old Jul 69 02 30 58.4 2.0N 90.0 old Jul 69 02 30 58.4 2.0N 90.0 old Jul 69 02 30 57.1 36.4N 70.0 old Jul 69 06 30 57.1 36.4N 103.0 old Jul 69 00 35 05.5 old Jul 69 00 36 05.2 old Jul 69 16 35 24.8 39.7N 74.	ntic Ridge	-			69		0		3		5	7.	
Der 28 Jun 69 11 16 01.0 7.4N 82. 28 Jun 69 04 34 42.6 12.8N 89. 26 Jun 69 02 30 58.4 2.0N 90. 26 Jun 69 02 30 58.4 2.0N 90. 27 Jun 69 09 47 59.4 59.5N 144. 18. 27 Jun 69 06 30 57.1 36.4N 70. 19. 28 Jun 69 06 29 53.9 57.5N 153. 28 Jun 69 06 29 53.9 57.5N 153. 10 Sep 69 17 41 25.0 18.0N 103. 11 Sep 69 17 25.0 18.0N 173. 22 Jun 69 00 35 05.5 11.7N 85. 22 Jun 69 00 35 05.5 11.7N 85. 19 Jun 69 07 03 04.9 28.1N 130. 19 Jun 69 07 03 04.9 28.1N 130. 28 Jul 69 10 45 24.5 51.5N 142.	f Chile		2			· ·	٦	0 21			18.15	-	
24 Oct 69 00 46 14.6 52.5N 168. 24 Oct 69 00 46 14.6 52.5N 168. 26 Jun 69 02 30 58.4 2.0N 90. 26 Jun 69 02 30 58.4 2.0N 90. 12 Oct 69 13 34 15.8 39.7N 20. 12 Oun 69 09 47 59.4 59.5N 144. 15. 27 Jun 69 06 30 57.1 36.4N 70. 15. 28 Jul 69 06 16 49 56.8 31.8S 177. 16. 29 Jun 69 06 29 53.9 57.5N 153. 10 Sep 69 17 41 25.0 18.0N 103. 10 Sep 69 17 41 25.0 18.0N 103. 10 Sep 69 17 41 25.0 18.0N 173. 10 Sep 69 17 41 25.0 18.0N 173. 11 Sep 69 14 22 15.0 6.7N 126. 12 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 16 35 24.8 39.7N 74. 28 Jul 69 16 35 24.8 39.7N 74. 28 Jul 69 15 37 56.2 24.1N 142. 19 Jun 69 15 37 56.2 24.1N 142. 10 3	Costa Rica .		, 4	Cac	69		,	1 ا	01.0		7.4N	82.7W	
24 Oct 69 00 46 14.6 52.5N 168. 26 Jun 69 02 30 58.4 2.0N 90. 12 Oct 69 13 34 15.8 39.7N 20. 12 Oct 69 13 34 15.8 39.7N 20. 12 Oct 69 13 34 15.8 39.7N 20. 12 Jun 69 06 30 57.1 36.4N 70. 15. 28 Jun 69 06 29 53.9 57.5N 142. 15. 22 Jun 69 06 29 53.9 57.5N 158. 10 Sep 69 17 41 25.0 18.0N 103. 10 Sep 69 17 41 25.0 18.0N 173. 11 Sep 69 17 41 25.0 18.0N 173. 11 Sep 69 17 41 25.0 18.0N 173. 11 Sep 69 17 41 25.0 18.0N 173. 12 Jun 69 00 35 05.5 11.7N 85. 12 Jun 69 10 45 24.5 51.5N 179. 14 Sep 69 16 35 24.8 39.7N 74. 14 Sep 69 16 35 24.8 39.7N 74. 14 Sep 69 16 35 24.8 39.7N 74. 18 Jun 69 07 03 04.9 28.1N 179. 19 Jun 69 16 35 37 56.2 24.1N 172. 10 37 05.2 <t< td=""><td>El Salvador</td><td></td><td>œ</td><td>Ung</td><td>69</td><td></td><td>0</td><td></td><td>42.6</td><td></td><td>•</td><td>6</td><td>/</td></t<>	El Salvador		œ	Ung	69		0		42.6		•	6	/
26 Jun 69 02 30 58.4 2.0N bania 12 Oct 69 13 34 15.8 39.7N 20. laska 02 Jun 69 09 47 59.4 59.5N 144. h 08 Aug 69 06 30 57.1 36.4N 70. 1s. 28 Aug 69 06 29 53.9 42.4N 142. 1s. 28 Jun 69 06 29 53.9 57.5N 153. inea 22 Jun 69 02 33 52.8 49.2N 153. inea 24 Aug 69 17 41 25.0 18.0N 103. inea 24 Aug 69 12 39 30.1 7.3S 148. e Is. 28 Jun 69 14 22 15.0 6.7N 126. 19 Jun 69 10 45 24.5 51.5N 179. 14 Sep 69 16 35 24.5 51.5N 179. 14 Sep 69 16 35 24.5 28.1N 142. 14 Sep 69 16 35 24.5 24.1N 142. 14 Sep 69 16 35 24.5 24.1N 142.	Fox Is.		4	Oct.	69		0	4		٥.	2	œ	
Damla 12 Oct 69 13 34 15.8 39.7N 20. laska 02 Jun 69 09 47 59.4 59.5N 144. h 08 Aug 69 06 30 57.1 36.4N 70. Is. 27 Jun 69 02 15 46.3 42.4N 142. Is. 28 Jul 69 06 29 53.9 57.5N 153. In. 22 Jun 69 02 33 52.8 49.2N 153. In. 22 Jun 69 02 33 52.8 49.2N 153. In. 24 Aug 69 17 41 25.0 18.0N 103. In. 24 Aug 69 12 39 30.1 7.3S 148. In. 24 Jun 69 10 45 24.5 6.7N 126. In. 22 Jun 69 10 45 24.5 51.5N 179. In. 19 Jun 69 10 45 24.5 51.5N 179. In. 28 Jul 69 16 35 24.5 51.1N 142. In. 28 Jul 69 15 37 56.2 24.1N 142.	Galapagos			Oun			0		2		•	90.5W	
08 Aug 69 06 30 57.1 36.4N 70. 08 Aug 69 06 30 57.1 36.4N 70. 27 Jun 69 02 15 46.3 42.4N 142. 28 Jul 69 06 29 53.9 57.5N 153. 22 Jun 69 02 33 52.8 49.2N 153. 18 Oct 69 02 33 52.8 49.2N 153. 24 Aug 69 12 39 30.1 7.3S 148. 24 Jun 69 00 35 05.5 11.7N 85. 28 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 707 03 04.9 28.1N 130. 28 Jul 69 15 37 56.2 24.1N 142.	Greece-Albanta		12	Oct.			_	3 34	15.8		6	20.4E	
s. 28 Aug 69 06 30 57.1 36.4N 70. 27 Jun 69 02 15 46.3 42.4N 142. 28 Jul 69 06 29 53.9 57.5N 153. 22 Jun 69 02 33 52.8 49.2N 153. 10 Sep 69 17 41 25.0 18.0N 103. 18 Oct 69 08 44 00.0 52.5N 173. 18 Oct 69 08 30.1 7.3S 148. 24 Jun 69 00 35 05.5 11.7N 85. 15. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 \$ 07 03 04.9 28.1N 130. 28 Jul 69 \$ 16 35 24.8 39.7N 74.	Alaska		05	Cun			0	9 47	59.4	1	6		
27 Jun 69 02 15 46.3 42.4N 142. 28 Jul 69 06 29 53.9 57.5N 153. 22 Jun 69 02 33 52.8 49.2N 158. 10 Sep 69 17 41 25.0 18.0N 103. 18 Oct 69 08 44 00.0 52.5N 173. 24 Jun 69 00 35 05.5 11.7N 85. 22 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 70 03 04.9 28.1N 130. 28 Jul 69 70 30 44.9 28.1N 142.	Hindu Kush			Aug			0	س.				70.9E	
15. 28 Aug 69 16 49 56.8 31.8S 177. 2 2 Jun 69 02 33 52.8 49.2N 153. 2 2 Jun 69 02 33 52.8 49.2N 158. 10 Sep 69 17 41 25.0 18.0N 103. 11	Hakkaido		1	Jun			.0	_	4		2	•	
28 Jul 69 06 29 53.9 57.5N 153. 22 Jun 69 02 33 52.8 49.2N 158. 10 Sep 69 17 41 25.0 18.0N 103. 118 Oct 69 08 44 00.0 52.5N 173. 118 Oct 69 08 52.5N 173. 12 Jun 69 00 35 05.5 11.7N 85. 22 Jun 69 14 22 15.0 6.7N 126. 19 Jun 69 10 45 24.5 51.5N 179. 14 Sep 69 16 35 24.8 39.7N 74.	Kermadec Is.	,	28	Aug			-	4	56.		-	177.8W	
22 Jun 69 02 33 52.8 49.2N 158. 10 Sep 69 17 41 25.0 18.0N 103. 18 Oct 69 08 44 00.0 52.5N 173. 24 Jun 69 12 39 30.1 7.3S 148. 22 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 07 03 04.9 28.1N 130. 14 Sep 69 15 37 56.2 24.1N 142.	Kodiac Is.		œ	Jul	69	Į.	0	2	2	đ	7.	3	
in Sep 69 17 41 25.0 18.0N 103. 18 Oct 69 08 44 00.0 52.5N 173. 24 Aug 69 12 39 30.1 7.3S 148. 24 Jun 69 00 35 05.5 11.7N 85. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 07 03 04.9 28.1N 130. 28 Jul 69 15 37 56.2 24.8 39.7N 74.	Is.		2	Jun			0	2 3	သ				
inea : 24 Aug 69			2	Sep	69		,	7 4			18.0N	. 103.4W	
e Is. 24 Aug 69 12 39 30.1 7.35 148. 24 Jun 69 00 35 05.5 11.7N 85. 28 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 16 75 24.8 39.7N 74. 58 Jul 69 15 37 56.2 24.1N 142.	Near Is.		78	Oct	69		0	8 4	0.00		52.5N		
e Is. 24 Jun 69 00 35 05.5 11.7N 85. 28 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 20 07 03 04.9 28.1N 130. 14 Sep 69 16 35 24.8 39.7N 74. 28 Jul 69 15 37 56.2 24.1N 142.	Guinea		24	Aug	69		Ī	2 3			7.35	148.15	
e Is. 28 Jun 69 14 22 15.0 6.7N 126. 22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 20 10 6.5 24.8 39.7N 74. 28 Jul 69 15 37 56.2 24.1N 142.	Nicaragua		24	Jun			0	. ന			11.7N	85.7W	
22 Jun 69 10 45 24.5 51.5N 179. 19 Jun 69 2 07 03 04.9 28.1N 130. 14 Sep 69 16 35 24.8 39.7N 74. 28 Jul 69 15 37 56.2 24.1N 142.	Philippine Is.			Jun			_	4 2	_			•	
. 19 Jun 69 # 07 03 04.9 28.1N 130. 14 Sep 69 16 % 24.8 39.7N 74. 28 Jul 69 15 37 56.2 24.1N 142.	Rat Is.		22	Jun			_	4	5 24.5		_	•	
14 Sep 69 16 % 24.8 39.7N 7. IS 28 Jul 69 15 37 56.2 24.1N 14	Ryukyu Is.		19	Jun		eb	0	7 0					
Is., 28 Jul 69 15 37 56.2 2	Sinklang		7	Sep	69			#1	5 24.8		39.7N	. 74.9E	
	Volcano Is.		28	Jul	69			5 3				142.7	

TABLE 111
Amplitude Data for Vertical Compone
Deans with Individual Traces B

								UÈO				-		1	1			
			-	1	SIGNAL		T			r -	6.00				_	61 <i>6</i> 2.41	b	1
					21005			HOISE			\$/11					SIGNAL		
	EVENT NO.	EVEAT	1	REAR	ľ	EMEAN	e Tus	ĭ	Emms	MEAR	Σ	E/REAR	46,4	1	MEAN	Ĩ	MEAN.	0η <u>105</u>
	1	Albaula	7	133	119	-1	15	6	-7	•	19	7	6.5	7	215	201	-1	19
	2	Argentina	5	720	562	-2	12	4	-9	50	137	7	7.0	(5)				
	. 3	6. Atlantic	6	184	169	-1	12	6	-6	10	29	4	7.6	7	161	58	-9	26
	4	A. Atlautic Midge	7	746	721	•	16	•	-6	49	91	5	6.5		878	359	-6	16
	- 5	Coast of Chile	6	930	708	-2	15	7	-6	64	96	3	7.6	4			11 23	
	6	Costa Mica	7	1101	1068	•	11	3	-12 ,	100	393	11	8.5					
٥	7	El Salvader	. 7	1939	1309	-3	12	5	-7	186	249	3	6.5	3 '	1579	1095	-3	
	•	Fex 1s.	6	650	685	-1	37	•	-13	10	78	12	7.6	1 7	310.	250	-2	22
	9	Ga lapages	7	7671	7326		11	5	-6	729	1372	5	6.5	/	381	306 '	-2	21 .
	18	Greece - Albania					•							4.	187	163		15
	11	Gulf of Alaska												1				
	12	Mindu Kusb	- 6	1276	1266		12	6 °	-6	163	215	6	7.8	7	645	799	•	27
	13 .	Hekkeide	7 .	646	587	-1	12	6	16	61	102	4 .	6.5	1	97		-1-	. 9
	14	Kermadec 1s.	6	1344	1226	-1	124	36	-10	11	32	18	7.0	7	616	682	. 46	- 178
	15	Rediac 1s.	6	1709	1761	•	14	5	1.	128	313	•	7.6	, 3	652	754	-1	. 12
	16	Kurile Is.	7	401	469	•	45	35	/ -2	11	13	2	8.5	1	200	261	1	.30
	17	Mexice											~		47			
	18	Sear 1s.							/					1			-	
	19	E. New Guinea	6	166	161		14	•/	-5	. 12	20	5	. 7 ,6	5	216	193	-1	20 '
	20	Micaragua	6	691	675	5	14	6	-8		121		7.6	3	609	608		13
	21	Philippine Is.					M. S.	. /				A.		8				
	22	Ret 1s.	7	6000	5999		13	1 6	-7	464	1812	7	8.5			4		
	23	Systys Is.					1	/		-		12	%					
	24	Stuktang	6	706	594	-2	×43 /	11	-7	31	55	5	7.0	7	1135	884	-2	23
	25	Volcane 1s.	f 6	163	89	-1	11/	4	-9	16	24	4	7.6	4	59	29	-6	11
							/					_						

1ABLE 111

mplitude Data for Vertical Component Long Period Array

Seems mith individual Traces Band Pass Filtered

				- 8	TFO :				Ç	. X., il	11				19	LASA	3 -		3	, 0	4)	1
		SIGNAL	1		MOISE	, ε		\$/11					SIGNAL		Y	HOISE		c	S/N			1
•	SEAN	ž	EMEAN	. 25	Ĭ	E ans	MEAN	Σ	E/MEAN	100	2	MEAN	Ì	ENEAD	n My PMS	Ì	E RMS	MEAN	Σ	E/MEAN	4	
, .	215	281		19		-9	11	- Jo		8.5		1	-	1000	-	-	-		4	24-1-1		
٠	_			t _i				45-	1		. •	6.2					4			4		
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	•	1	٠.		(¢,			·	1.7	466	372		72	3	-11	42	107		12.3	<u></u>
	•										16	1217	990	-2	12	5	6	102	188	5	12.8	
5	216	193	-1	28	11	-5	13	. 18	1.3	7.0	17	151	126	·2 °	15	4	-10	10	28	•	12.3	
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•] 1 e			۵			4,1			-41	-14	134	113	-1	11	4	0-9	12	je	18	11.5	
			· II,	ı.			•		•		15	4838	4242	-1	14	7	-6	378	636	ts	11.8	
	44				- 1					•-	c 14	250	193	-2	22	6	-11	11	31	1. 9	11.5	
7	1135	884	-2	23	11	-5	50	¥	3	8.5	,	14		8				14		1		
4	59	29	-6	(11)	7	+4		4	-1	. 6.0						40	1			i.		

B

TABLE ...

Amplitude Data for Vertical Component Long Period Array Beams using LASA . C or F Ring Instruments with Individual Traces Band Pass Filtered

\													
0				SI	SIGNAL		i i	NOISE		2	S/N		14
EVENT	INSTRUMENTS	GROUP VEL. OF BEAM	21	MEAN	弘	2/HEAN	n r	a	Ωd r s s s	HEAN	W	ZHEAN	
SEE MC	Costs Rica AOZ and C-ring: 3.0 km/sec	3.0 km/sec	S	. 750	722	£	~	. 🕶	-5.2	96	194	6.1	. 1
Costa Rica	AOZ and C-ring 3.8 km/sec	3.8 km/sec	•	750	727	£	1	•	*.	96	178	5.5	
Costa Rica	AOZ and F-ring 3.0 km/sec	3.0 km/sec	S	1124	809	-5.3	=	S	-7.3	96	124	2.2	
osta Riga	Costa Risa _A02 and F-ring 3.8 km/sec	3.8 km/sec	40	1124	952	-1.4	Ξ	S	-6.3	96	174	5.2	

TABLE V
Amplitude Oata for Vertical Component Long
Beams, with Individual Traces Low Pass Fi U80 ° TFO 216H**Ý**L HOISE SIGNAL MOISE MEAR ERNS MEAN E E/MEAN MEAN T EMEAN 7630

Amplitude Bata for Vertical Component Long Periad
Reams with Individual Traces Low Pass Filtered

					TFO			٥		ъ.	17.4	43 .			LASA		.1			1
,		SIGNL			NOISE			- S/11			-	SIGN	AL .	٠,٠	HOISE			S/N	. 0	
4.	HEAT	Ĩ	EMEAN	eu res	Ì	E RMS	HEAD	Σ.	E/HEAN	db b	<u>.</u>	HEAN E	EMEAN	* <u>**.</u>	Ž / -	Δb E/ans	MEAN	Σ.	Z/MEAN	40 h
4.	99	92	-1-	58	41 /	-3	. 1	2	,+2	6.0	16 -	1040	193 -1	, 111	42	-8	•	21	, , , ;	12.0
1 1	61	33	-5	32	17	-6	٠٠ ٠٠ ٢	2		6.0	-14	247 1	91 -2	. 23	,	-11	10	29 0 v	•	11.5

TABLE VI

Amplitude Data for Horizontal Component Long Period Array. Beams with Individual Traces Band Pass, Filtered

EVENT NOISE NOISE E-W ML	Ø.	3 0			0		٥	0					0 65				
1c. 7 35 20 -5 6 29 15 -6 Is. 7 96 29 -10 6 138 50 -9 7 Is. 7 6 6 69 34 -6 5				IOISE		a	NOI	S 3	8		NO I SE	W			2	NOISE E-W	9,
1c. 7 35 20 -5 6 29 15 -6 1s. 7 96 29 -10 6 138 50 -9 7 1s. 7 6 6 69 34 -6 5			. 0	2			-		4		1	2	qp		ne	1	9
1c. 7 35 205 6 29 15 -6 1s. 7 96 29 -10 6 138 50 5 -9 7 7 6 6 69 34 6 -6 5		° 21	로입	EM	Surms.	 Zi	SEL SEL	M	E/rms	ZL.	Z S	М	Z/rms	ZI	rms	4	3
Is. 7 .96 29 -10, 6, 138, 50 3-9 7.	Atlantic	1	35	20	-5	9	. 29	15	10.			e na		000		X	
1s. 7 .96 29 -10, 6, 138 .50 -9					4		,		,	0	104	33	-10	7	122	37	2
. 6, 76, 33 -7 6 . 69 34	madec "Is.	1	96°	53	0.	6	رة 138	20	D "		5	3	•		Ę		*
	/a	•	92	33	-1	" '	. 69	34	9	S	80	24	£-	a *	87	S.	4
	ė	e 5		,	0		K			ď	2	12	ا ا	S	20	. 28	- 5

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13 ABSTRACT

Long period signals recorded at the seismic arrays UBO, TFO and LASA were analyzed to determine the fundamental mode Rayleigh wave dispersion curves for paths from different source areas to each of the arrays. These paths are mixed continental and oceanic, and the dispersion curves calculated fall within the range between the average dispersion for a pure continental path and that for a pure oceanic path. Analysis of the long period noise (15 to 50 seconds) recorded at each array shows the rms value to be in the 8 to 20 mu range. Simple beamforming gives approximately N3db reduction in noise at all arrays. Using a group velocity of 3.5 km/sec results in signal loss for some events in the LASA beams.

Long period signals
UBO, TFO and LASA
Rayleigh wave dispersion

Beamforming rms

Unclassified